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LEVEL II

DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-78-28

DREDGED MATERIAL TRANSPORT SYSTEMS FOR INLAND DISPOSAL AND/OR PRODUCTIVE USE CONCEPTS

by

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McLean, Virginia 22101

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June 1978
Final Report

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Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Contract No. DACW39-76-C-0026
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31 July 1978

SUBJECT: Transmittal of Technical Report D-78-28

TO: All Report Recipients

1. The technical report transmitted herewith represents the results of one of several research efforts (work units) undertaken as part of Task 3B, Upland Disposal Concept Development, of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 3B, part of the Productive Uses Project (PUP), had a general objective of determining the feasibility of inland disposal of dewatered dredged material.

2. Because of increasing constraints on open-water disposal of dredged material, the Corps of Engineers has had to resort more and more to land disposal. In the past, land disposal sites have been located close to the dredging project, primarily to minimize material transport costs, afford easy access by water, and allow effluent to return to the waterway. However, location of new land disposal areas near dredging projects is severely constrained by environmental and land-use considerations. Consequently, the primary objective of this study was to identify and evaluate transportation systems for the movement of dredged material inland to areas with higher potential for acceptable disposal.

3. Pipeline slurry (hydraulic and pneumatic), rail haul, barge movement, truck haul, and belt conveyor transportation alternatives were analyzed on the basis of technical and economic considerations for the movement of large quantities of dredged material over relatively long distances. For all but the pipeline slurry mode, the material being moved was assumed to be in a relatively dry form. It was also assumed that the dredging system would not be part of the long-distance transport system and that all long-distance transport would originate from a rehandling facility. Annual quantity of movement was varied from 500,000 to 5,000,000 cu yd while the distance was varied from 6 to 325 miles.

4. It was concluded that generally the truck haul and belt conveyor systems would be the most expensive, irrespective of the annual volume and distance of movement. Hydraulic pipeline movements were generally

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the cheapest although as volumes and distances increased, barge and then rail systems became more economical. Cost of transportation varied considerably depending on the system, annual volume, and distance transported. The cost varied from a low of $0.80 per cu yd for hauling 5,000,000 cu yd/per year 20 miles by hydraulic pipeline to a high of $34.00 per cu yd for moving 500,000 cu yd/per year 60 miles by conveyor belt.

5. The report offers costs estimates and comparison of estimates for planners and engineers to use in evaluating the economics of transporting dredged material long distances inland. It also contains a detailed methodology for designing long-distance hydraulic transport systems for dredged material movement.

JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

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The purpose of this study is to identify and evaluate transportation systems applicable for the movement of dredged material inland. As such, this report is intended to provide the Corps of Engineers with generalized data which can be utilized in evaluating the economic potential of inland disposal alternatives for specific applications across the country. In this regard, considerable detail from both a technical and economic point of view is next page

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20. ABSTRACT (Continued).

provided to allow the users of this report to apply the information presented herein to their particular situations. Where a given application requires modification in a specific transportation concept and/or an alteration in specific cost elements, the level of detail in this report should facilitate any such required changes.

Five basic transportation modes have been examined in this study: pipeline slurry, rail haul, barge movement, truck haul, and belt conveyor movement. Combinations of these basic modes have been considered where appropriate. The dredged material which is to be transported is considered to be in either a slurry or a "relatively" dry material form. The slurry form will vary in density depending on the type and gradation of the material and the specific application under consideration. In this study the only transportation mode that is examined for the movement of a slurry mixture is the pipeline alternative. For the pipeline movement of dredged material in a slurry state, varying slurry and in situ densities are examined. The other transportation modes are concerned with the movement of relatively dry material because hauling large quantities of water is uneconomical.

The distances over which the dredged material is to be moved vary from about 6 to 300 miles. For a given application, the annual volume of movements examined in the study varies from 500,000 to about 5,000,000 cubic yards per year.

A final consideration associated with this study is that the results presented herein have been developed for a generalized application of the movement of dredged material from point A to point B anywhere across the country. It is recognized that each application will have unique features such as terrain, weather conditions, labor rates, etc. Given the potential myriad of applications which may occur, it would be impossible to cover all situations in this report. Therefore, it was acknowledged that this is a generalized study to be used as a guide in transportation planning but not in the absolute prediction of transportation costs for a given situation.

SUMMARY

Purpose and Scope

The purpose of this study was to identify and evaluate transport systems applicable for the movement of dredged material inland. As such, this report is intended to provide the Corps of Engineers with generalized data which can be utilized in evaluating the economic potential of inland disposal alternatives for specific applications across the country. In this regard, considerable detail from both a technical and economic point of view is provided to allow the users of this report to apply the information presented herein to their particular situations. Where a given application requires modification in a specific transportation concept and/or an alteration in specific cost elements, the level of detail in this report should facilitate any such required changes.

Five basic transportation modes were examined: pipeline slurry, rail haul, barge movement, truck haul, and belt conveyor movement. With regard to the pipeline slurry analysis, two pumping methods were analyzed, centrifugal pumping systems and Pneuma pumping systems. No attempt was made to evaluate the viability of potential productive uses or the suitability of inland disposal.

Approach

The following activities were performed by the study team in the conduct of the study effort:

- Conducted an in-depth literature review of prior studies involving technical and economic aspects of alternative transportation modes (pipeline, rail, truck, barge, and belt conveyor.

- Conducted research on the technical aspects of hydraulic pipeline-transportation, rail haul, barge movement, truck haul, and belt conveyor transportation modes.

- Developed detailed design data and parameters for the hydraulic pipeline transportation alternative.

- Derived detailed, total, and unit cost estimates (including material handling costs as well as transportation costs) for each transportation alternative based upon varying annual quantity movements over varying distances. Annual quantity movements ranged from 500,000 to 5,000,000 cubic yards per year for each application, and distances were varied from six to 300 miles.

- Developed a computer model to derive design and cost data for centrifugal pump slurry pipeline transport systems.

- Utilizing the computer model, conducted sensitivity analyses to determine effect on total costs of varying the values of several of the principal design parameters and cost elements.

- Conducted a comparative analysis of transportation alternatives based upon *technical and economic considerations.*

- Additionally, the study team identified legal, institutional, environmental, and other potential constraining considerations to be examined prior to the implementation of a desired transportation alternative.

Findings

General

The findings presented are based on the assumptions made and discussed in the main text of this report. These findings should be regarded as generalized evaluations of the related costs of selected transportation modes under representative operating conditions. When specific applications are considered, the unique aspects of each application should be evaluated individually and more precise costs related to each specific application be derived. It should also be noted that cost estimates provided in this study are expressed in 1976 dollars. These estimates can be converted to current dollars by adjusting for price changes that occur between 1976 and the time a specific application is considered.

Overall, it was observed that irrespective of the annual volume of movements the belt conveyor and truck haul systems are considerably more expensive than pipeline, rail, or barge transportation systems. At the 500,000-cubic yard annual volume movement level, hydraulic pipeline transport is the most economical mode for distances up to about 20 miles. Beyond this distance and up to the limiting distance of this study, movement by barge is the most economical transport system. Movement by hydraulic pipeline is more economical than movement by rail up to a distance of about 60 miles. Beyond this point rail movement becomes less costly than pipeline movement. Therefore, for those applications where barge haul is not flexible (lack of suitable waterway to support barge to transport) the tradeoff point between hydraulic pipeline transport and rail transport is at the 60-mile distance.

When this annual volume movement level is increased to 1,000,000 cubic yards, the distance to which hydraulic pipeline transport is the most economical, increased from 20 to 50 miles. Barge haul is still the most economical beyond that point; however, where barge haul is not feasible the tradeoff point between rail and hydraulic is at the 75-mile distance.

At the 3,000,000-cubic yard annual movement level, hydraulic pipeline transport is the most economical up to a distance of about 115 miles. Up to and beyond this point, rail movement is now more economical than barge haul. As the annual volume movement increases above this level there are no significant changes in the above cost pattern except that hydraulic pipeline transport is the most economical up to its 125 mile practical limitation.

- <u>Hydraulic Pipeline Transport</u>. For annual volume movements of 500,000 cubic yards, total hydraulic pipeline transport costs (dollars per cubic yard) will vary from about $2.75 per cubic yard at 20 miles to about $10.00 per cubic yard at 120 miles. For annual volume movements of 5,000,000 cubic yards, total hydraulic pipeline transport costs will

vary from about $0.80 per cubic yard at 20 miles to about $3.60 per cubic yard at 120 miles. From these data it is apparent that for hydraulic transport of dredged material unit costs (dollars per cubic yard) will drop significantly for the larger volume movements. It is also observed that for distances under about 50 miles, hydraulic transportation of dredged material inland is the economic choice among transportation modes in all instances for volume movements in excess of 1,000,000 cubic yards per year.

The total costs associated with centrifugal and Pneuma pumping systems are closely comparable. In some instances centrifugal pumping is the more economical and in other instances Pneuma pumping will be the more economical. However, the tradeoff between the two pumping systems is so close that each one should be evaluated separately based upon the unique requirements of the case.

- Rail Haul. For annual volume movements of 500,000 cubic yards, total rail haul rates (dollars per cubic yard) will vary from about $5.80 per cubic yard at 50 miles to about $8.90 per cubic yard at 300 miles. For annual volume movements of 5,000,000 cubic yards, total rail haul rates will vary from about $3.00 per cubic yard at 50 miles to about $6.10 per cubic yard at 300 miles. The large reduction in total rail haul costs associated with larger volume movements can be attributed to reduced material handling unit costs (loading and unloading) and reduced transportation unit rates.

The break-even point between rail and barge haul for transporting dredged material inland occurs at annual volume levels of about 2,000,000 cubic yards. At higher annual volume levels, rail haul will be more economical; at lower annual volume levels, barge haul appears more economical (all other factors considered equal). In every case between 50 and 300 miles, rail haul appears to be more economical than either truck haul or belt conveyor movement.

• Barge Haul. For annual volume movements of 500,000 cubic yards, total barge haul rates (dollars per cubic yard) are estimated to be about $3.40 per cubic yard at 50 miles and about $7.40 per cubic yard at 300 miles. For annual volume movements of 5,000,000 cubic yards, total barge haul rates are estimated to be about $3.15 per cubic yard at 50 miles and about $7.20 per cubic yard at 300 miles. Since barging costs, both material handling and transportation elements, are considered to be closely related to volumes transported, only marginal cost reductions are observed in transporting larger annual volumes of material.

Overall, the results of the analysis indicate that for the lower annual volume movements, barge haul is one of the most economic means to transport dredged material inland. At the 500,000-cubic yard level, barging becomes the most economical option for distances in excess of 20 miles. At the 1,000,000-cubic yard level, the pipeline versus barging break-even point occurs at about the 50-mile point.

• Truck Haul. For annual volume movements of 500,000 cubic yards, total truck haul costs will vary from about $7.75 per cubic yard at 30 miles to about $13.40 per cubic yard at 120 miles. For annual volume movements of 5,000,000 cubic yards, total truck haul costs will vary from about $6.20 per cubic yard at 30 miles to about $12.00 per cubic yard at 120 miles. Large-scale truck haul movements will yield reductions in unit costs; however, in comparison with other transportation alternatives, truck haul of dredged material is not closely competitive. In every case, where direct comparisons are valid, pipeline slurry, rail, and barge haul are more economical than the truck haul option. The underlying reasons for these results can be many, but the most notable is that for the large annual volumes under consideration in this study, truck haul is a labor and fuel intensive mode of transportation in comparison with other transportation modes.

• Belt Conveyor Movement. At the lower annual volumes, belt conveyor unit costs (dollars per cubic yard) are dramatically higher than any of the other competing transportation modes. However, at the higher annual cubic yard volume levels and over small distances (less than 20 miles) belt conveyor movement becomes competitive with all transportation alternatives except the pipeline slurry option. This result depicts the economic nature of belt conveyor transportation which is its high investment cost but inherent ability to move extremely large annual quantities of bulk materials.

Recommendations

Based upon the technical considerations and cost derivation assumptions followed in the study, pipeline slurry transportation is the most economical choice in most instances for distances up to about 100 miles but only where annual quantities exceed 1,000,000 cubic yards. For longer distance movements, barge or rail haul will be the most economical selection depending on annual volumes to be transported. Generally, rail becomes the more economical choice at the higher volumes.

As discussed in the text of the report, care must be taken in comparing cost data between transportation modes because each mode requires a specific transport route (rail line, waterway, etc.) which in the majority of instances will result in varying distance movements associated with each transportation mode for a given application. It should also be noted that, as discussed in Part III of this report, in some cases combinations of transportation modes may be required to transport dredged material to an inland site. It is possible for a specific application that barge and truck haul, or barge and pipeline slurry modes, as well as other potential combinations, could be utilized. For economic evaluation of these cases, unit costs can be easily combined to evaluate the total transportation system's cost. However, care must be exercised to avoid double counting of the material handling activity at the point where the two transportation modes interface.

Unless unusual circumstances exist for a given application, the following practical distance limits are recommended for each transportation mode.

- Hydraulic Pipeline Transport. It is recommended that the pipeline alternative be considered for distances up to about 125 miles. Distances in excess of 125 miles will increase the potential for system breakdown because of the increasing number of booster stations required.

- Rail Haul. Rail haul should be considered for distance movements between 50 and 300 miles. At distances below 50 miles, available cost data are only fragmentary.

- Barge Haul. Barge haul can be considered for all applications where suitable waterways exist.

- Truck Haul. Truck haul should only be considered for distances up to about 50 miles. Movement of large quantities of dredged material in excess of 50 miles will be very uneconomical.

- Belt Conveyor. Belt conveyor movement is best considered for those applications where very large volumes are required to be moved short distances. Practical distance limits for belt conveyor applications will be under 50 miles.

In selecting the most desirable transportation alternative, it is recommended the following sequence be followed.

- Identify the available transportation routes and their respective distances for the movement of dredged material inland. In many cases a transportation alternative may be eliminated for lack of a suitable transportation route.

- Identify the nature and characteristics of the material to be transported (i.e., wet or relatively dry state, in situ density).

- Determine the annual volume of material to be transported and the anticipated duration (years) of the project.

- Derive estimated yearly costs for each transportation alternative based upon the methodology presented in this report. If cost data which are presented herein are utilized, care should be taken to update these data as required for the application under consideration.

• Evaluate additional technical, legal, environmental, and institutional considerations for each mode to ensure the practicality of the application.

• Select the desired transportation alternative.

The above generalized procedure coupled with the detailed design and cost derivation methodology contained in this report will serve as a guide in evaluating among transportation systems for the movement of dredged material inland.

The final recommendation is that several case studies involving the application of these engineering and economic data to the specific requirements of actual cases be conducted. The performance and documentation of selected case studies would be a valuable supplement to this report.

PREFACE

The work described in this report was performed under Contract DACW 39-76-C-0026, titled "Dredged Material Transport Systems for Inland Disposal and/or Productive Use Concepts," dated October 1975, between the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, and the General Research Corporation (GRC), McLean, Virginia. The research was monitored by the Environmental Laboratory (EL), WES, under the Dredged Material Research Program (DMRP) Work Unit No. 3B01, and sponsored by the Office, Chief of Engineers, Washington, D.C.

This report presents a technical description and economic evaluation of alternative transportation systems for the transport of large annual quantities of dredged material relatively long distances inland on a continuing basis. Pipeline slurry systems (centrifugal and Pneuma), rail haul, barge movement, truck haul, and belt conveyor transportation modes are evaluated.

The research was conducted under the supervision of Mr. Paul S. Souder, Jr., Project Director. Participating with him were Mr. Leo Tobias, P.E., and Ms. Frances C. Mushal. Also assisting as technical consultants were Mr. Louis J. Mauriello, P.E., and Dr. John B. Herbich, Director, Center for Dredging Studies, Texas A&M University. GRC staff contributing to the preparation of this report include Ms. Ruth Eanet, Ms. Bonnie Hurwitz, and Ms. Kathlyn Spaur.

During the conduct of the study, GRC representatives met with a number of Corps of Engineers District personnel who provided background data for the study.

The contract was monitored by Mr. Michael R. Walsh. The report was prepared under the general supervision of the manager of the Productive Uses Project (PUP), Mr. Thomas R. Patin. Dr. Roger Saucier and MAJ Robert Meccia were also managers of the PUP during the research phase of the project. Dr. John Harrison was Chief of the EL. Other EL personnel who participated included Mr. Charles C. Calhoun and Mr. Ray Montgomery.

The Directors of WES during the study and preparation of the report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
yards	0.9144	metres
miles (S.S. statute)	1.609344	kilometres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
pounds (mass)	0.4535924	kilograms
tons (2000 lb, mass)	907.1847	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
horsepower	745.6999	watts
pounds (force) per square inch	6894.757	pascals
atmospheres	98066.50	pascals
feet per second	0.3048	metres per second
miles per hour	1.609344	kilometres per hour
feet per second^2	0.3048	metres per second^2
gallons (U.S. liquid) per minute	3.785412	cubic decimetres per hour
cubic feet per second	0.02831685	cubic metres per second
cubic yards per hour	0.07645549	cubic metres per hour
cubic yards per mile	0.4750723	cubic metres per kilometres
tons (2000 lb, mass) per hour	907.1847	kilograms per hour

PART I: INTRODUCTION

The dredged material transport study presented herein is concerned with the identification, examination of technical feasibility, and economic evaluation of alternative transportation modes for moving large volumes of dredged material relatively long distances inland for disposal and/or productive uses. As such, this study is a transportation study and no attempt has been made to investigate or analyze the technical feasibility of inland disposal sites and/or productive uses.

Background

The U.S. Army Corps of Engineers is responsible for maintaining about 22,000 miles of inland waterways, 3000 miles of intracoastal channels, 100 commercial port facilities, and approximately 400 smaller ports and harbors throughout the Nation. Domestic waterborne commerce, including inland barge and Great Lakes traffic, presently moves one-sixth of the Nation's cargo that travels between cities by all methods of transportation, and the traffic on waterways continues to increase at a compound rate of slightly more than 5 percent per year. It is predicted that the volume of this traffic, such as grains, ores, chemicals, fuels, and construction materials, will increase from four to six times in the next 50 years.

The volume of maintenance dredging required annually to restore project dimensions on existing Federal navigation projects by removing natural or man-induced shoal material is presently averaging slightly more than 300 million cubic yards per year. In carrying out the responsibility for improving and maintaining the Federal navigation

projects, the Corps accomplishes the major part of the dredging work by hydraulic dredging equipment, mainly seagoing hopper dredges and cutterhead pipeline dredges. The remaining workload is accomplished by mechanical dredges, e.g., bucket, dipper or sidecaster dredges or, in the case of the Mississippi River and tributaries, by hydraulic dustpan dredges.

The selection of the type of dredge most suited for a particular job is dependent on several factors such as the characteristics of the material to be dredged, the location of the place of disposal of the material, prevailing weather and sea conditions, and traffic. With the increased concern over water quality, the selection of the best type of dredge to accomplish the work becomes more complex.

Although plant efficiency is an important consideration in selecting the dredging tool for a particular job, the method of disposal is also a factor. Until recently, disposal practices were generally limited to the more economical of two choices: open-water disposal or disposal on upland areas or wetlands. Thus, on the basis of selecting the most economical method of disposal, about two-thirds of all material dredged in past years, both new work and maintenance, was deposited at selected disposal sites in open water. These open-water sites were located near enough to the dredging sites to minimize hauling costs but at locations where direct influences on beaches, water intakes, or other facilities were minimum.

Problems associated with the deposition of dredged materials in open waters are generally minor where the dredged material is classified as non-polluted. However, where bottom sediments are considered to be polluted, feasible alternatives to open-water disposal of the dredged material must be sought. As a result of the concern over open-water disposal of polluted material, there probably will be more upland disposal of dredged material in future years. Most of the material which will have to be disposed of on land will come from

highly developed areas (e.g., harbors and estuaries) where land disposal sites are and will be increasingly more difficult to obtain. It is the general view of concerned Federal agencies and waterway users that in eight to ten years suitable nearby upland disposal areas will be almost nonexistent in many of the major waterway projects.

The expanded use of land disposal will require the employment of barge, pipeline, truck, or rail haul systems to transport the material longer distances inland. Since pipelines and barges have long played a part in dredging operations, the consideration of these transportation modes for moving dredged material inland is a natural extension of existing usage. When the question arises of transporting dredged material in very large quantities over long distances, it is also logical that truck and rail haul be considered. Finally, with the advancement in technology in the belt conveyor field, belt conveyor movement of dredged material must also be considered.

Purpose

The purpose of this study is to identify and evaluate transport systems applicable for the movement of dredged material inland. As such, this report is intended to provide the Corps of Engineers with generalized data which can be utilized in evaluating the economic potential of inland disposal alternatives for specific applications across the country. In this regard, considerable detail from both a technical and economic point of view is provided to allow the users of this report to apply the information presented herein to their particular situations. Where a given application requires modification in a specific transportation concept and/or an alteration in specific cost elements, the level of detail in this report should facilitate any such required changes.

Scope

Five basic transportation modes have been examined in this study: pipeline slurry, rail haul, barge movement, truck haul, and belt conveyor movement. Combinations of these basic modes have been considered where appropriate. The state of the dredged material which is to be transported is considered to be in either a slurry or a "relatively" dry material form. The slurry form will vary in density depending on the type and gradation of the material and the specific application under consideration. In this study the only transportation mode that is examined for the movement of a slurry mixture is the pipeline alternative. For the pipeline movement of dredged material in a slurry state, varying slurry and in situ densities are examined. The other transportation modes are concerned with the movement of relatively dry material because hauling large quantities of water is uneconomical.

The distances over which the dredged material is to be moved vary from about 15 to 500 miles. While this spread is quite large, it can be seen from the results of this study that there are varying practical distance limits for each transportation mode under consideration. For a given application, the annual volume movements examined in the study vary from between 500,000 to about 5,000,000 cubic yards per year. It is believed that this range covers all generalized large volume movements which may be anticipated. For volumes under 500,000 cubic yards per year, it will be very difficult to realize the economies of scale required to achieve the relatively low transportation rates derived herein.*

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* For annual volumes under 500,000 cubic yards, it should be noted the methodology for cost derivations shown herein is suitable for usage; however, specific unit costs must be re-evaluated for appropriateness since economies from large-scale operations cannot be expected.

A final consideration associated with this study is that the results presented herein have been developed for a generalized application of the movement of dredged material from point A to point B anywhere across the country. It is recognized that each application will have unique features such as terrain, weather conditions, labor rates, etc. Given the potential myriad of applications which may occur, it would be impossible to cover all situations in this report. Therefore, it must be acknowledged that this is a generalized study to be used as a guide in transportation planning but not in the absolute prediction of transportation costs for a given situation.

Derivation of Economic Data

Basis for Utilization of Economic Data

Economic data presented herein represent estimated mid-1976 costs and no attempt has been made to allow for inflation into the future. Allowances must be made for the effects of change in cost indices.

Basically, two types of cost data are considered: fixed costs (i.e., capital costs) and variable costs (i.e., annual operating and maintenance costs). Fixed costs are extended to provide for capital recovery over the economic life of the equipment/facilities at a discounted rate of 7 percent per year. Variable costs represent total estimated annual operating and maintenance costs which are based upon a contractor run facility/operations. Wherever appropriate and desirable, especially where large expenditures for fixed equipment and facilities would be involved, government construction and ownership of the facilities with contractor operation is contemplated.

In many instances during the formulation of the operational scenarios of the alternative transportation modes, the option exists for each variation being examined (i.e., volume movements

and distances) to postulate either an operational cycle on the basis of a full year's activity with varying daily hourly operations, or an operational cycle which represents a full 24-hour daily activity with varying yearly utilization rates. This requirement arises from the fact that varying annual volume movements over varying distances will result in situations where full transportation system capacities do not require both full daily operations (i.e., 24 hours per day) and full yearly utilization (i.e., 280 days per year). Since in most instances it is more economical, practical, and desirable, the latter option of working a full 24-hour day at varying yearly utilization rates was selected as the approach for this study. The major exception to this methodology is in the case of the long-distance belt conveyor analysis, where economies of usage dictate a full yearly utilization at a reduced daily operational rate. The specific methodology utilized for each transportation mode is described in detail in each respective section of this report.

Every attempt has been made to ensure consistency in the costing of each transportation mode to permit valid comparisons between modes. Care should be taken to review the assumptions associated with the cost data for each separate transportation mode.

Sources of Cost Data

Many different sources provided the data for the cost estimates presented herein. In addition to the inhouse professional expertise, cost data and other pertinent information were derived from catalogues, manuals, and brochures, as well as correspondence and personal discussions with officials and representatives of the following organizations which are recognized as being exceptionally qualified in their respective fields:

- Field Offices of the Corps of Engineers, US Army
- Ellicott Machine Corporation, Baltimore, Maryland
- US Steel Corporation, Washington, D.C.
- Edison Electric Institute, New York, New York

- Norfolk and Western Railroad
- Chessie System
- Southern Railroad
- O'Boyle Tank Lines, Rockville, Maryland
- Chemical Leamon Tank Lines, Downington, Pennsylvania
- Robbins Engineers and Constructors (Litton Systems, Inc.), Totowa, New Jersey
- Krupp International, Inc., Harrison, New York
- Heyl and Patterson, Inc., Pittsburgh, Pennsylvania
- Dravo Corporation, Pittsburgh, Pennsylvania
- Bucyrus-Erie Corporation, South Milwaukee, Wisconsin
- Caterpillar Tractor Corporation, Springfield, Virginia
- Pneuma Corporation, Florence, Italy
- Ingersoll Rand Research, Inc., Princeton, New Jersey
- Ingersoll Rand (Air Power Division), Roselle, New Jersey
- Wilson-Snyder Pumps, Dallas, Texas
- Associated General Contractors of America, Washington, D.C.

PART II: DREDGING OPERATIONS AND INHERENT TRANSPORTATION SYSTEMS

Since this study is concerned primarily with the transport of dredged material in large quantities over relatively long distances, one must establish where the transport system commences. It must be recognized that inherent in every type of dredging operation whether accomplished by hydraulic, mechanical, or hopper dredge, there is also a transport system. Thus the question which arises in establishing the direction of the study is the determination of whether the navigation channel dredging operation itself together with its transport system should be considered a part of, or subsystem of, the overall long-distance transport system.

To make such determination, a review must be made of the effects which would result from including the channel dredging operations in the long-distance transport concept on the basic purpose, need, and requirements for the dredging operation by the Corps of Engineers. These basic elements, which derive from the vested responsibility of the Corps of Engineers for improving and maintaining the Federal navigation projects, in essence dictate that the navigation channel work be accomplished in a timely and efficient manner without undue delay so that adequate channel depths are available in the project waterways to support the normal movement of waterborne commerce. (One of the premises underlying this overall research study is that it encompasses only those dredging operations conducted by or for the Corps of Engineers.)

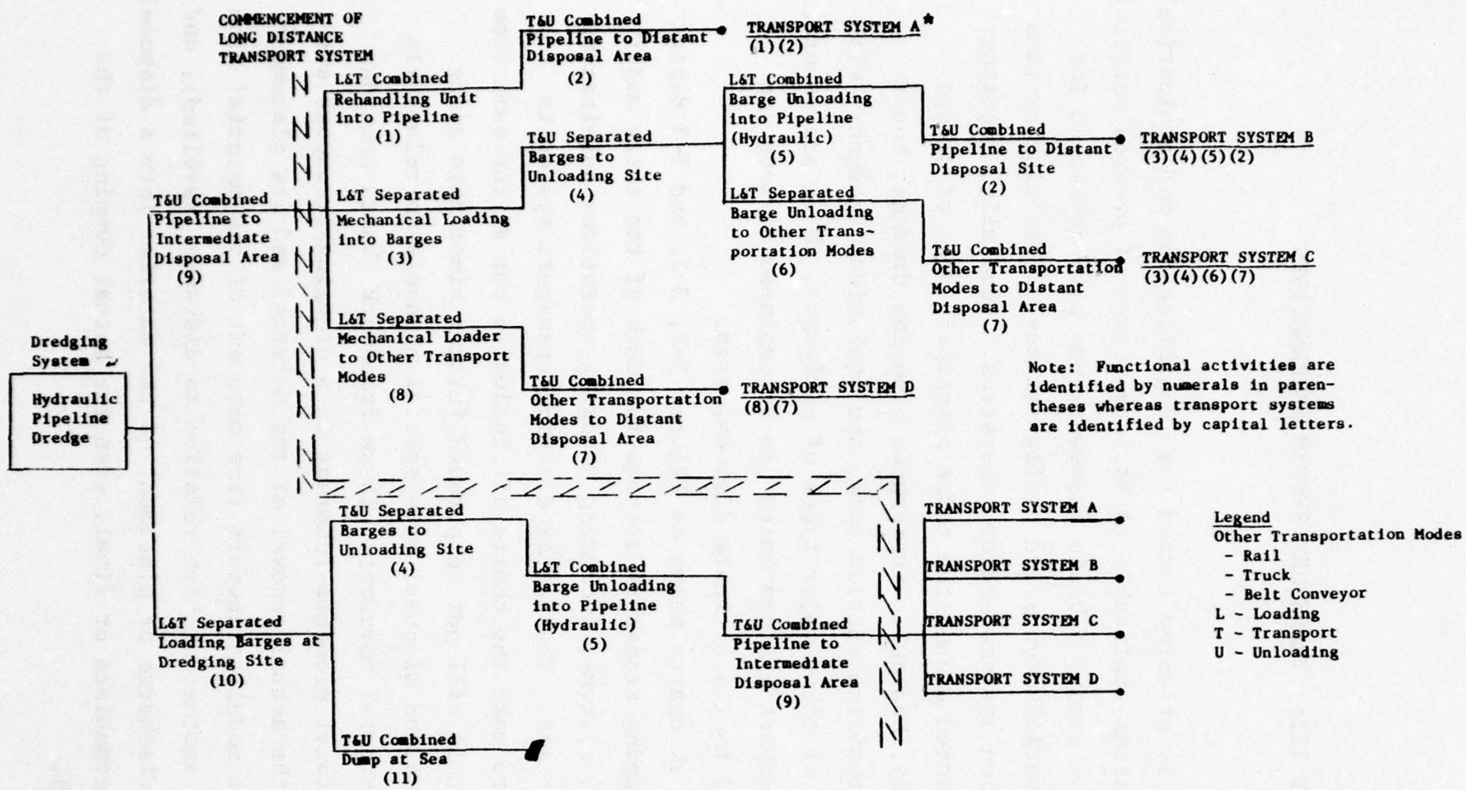
Such a review, included as Appendix A, was made and all pertinent factors and effects associated with the operations of the three principal dredging systems (hydraulic, pipeline, and mechanical) were considered and analyzed. This review led to the conclusion that the channel dredging operation itself with its inherent transport subsystem should not be included in the overall long-distance transport concept. To do so would generate unacceptable delays in the dredging operations, result in complex problems in scheduling and synchronizing the various operational phases of the work and require such costly modifications in operational procedures and controls that the transport concept would become impractical and economically infeasible. It was also concluded that any long-distance transport system should commence at an existing disposal area within which the dredged material was previously deposited. This concept, which forms the basis for the transport systems analysis in this report, is based upon the excavation of existing disposal areas which have reached or are nearing their full capacity, and the transport of the excavated material to a new distant disposal area. In this manner the original capacity of the existing disposal area will be essentially re-established and thereby permit the direct discharge therein of the material dredged from the nearby Federal navigation channels.

It has been recognized that for a hydraulic long-distance transport system, a question could arise that since the dredged material will already be in the pipeline, why not pump directly from the dredge through a series of booster stations to the distant disposal area. The rationale for not commencing the hydraulic transport system at the dredge operating in the channel is discussed fully in Appendix A.

PART III: TRANSPORT SYSTEM ALTERNATIVES

This study is oriented toward the identification and evaluation of transport systems applicable to various states of dredged material. To facilitate the study, a basic framework has been developed for discussing the various types and configurations of dredging systems and transportation systems and/or subsystems. Generally, dredging systems are oriented around the three principal types of dredge equipment; namely, hydraulic cutterhead pipeline dredges, hopper dredges of the trailing suction type, and mechanical dredges. With respect to each of these major types of equipment, there are several alternative transport systems which can be employed to move the dredged material to its ultimate disposal area.

The framework charts shown as Figures 3-1, 3-2, and 3-3 depict the various dredging transport systems for each of the three major dredge equipment systems, including dredging operations culminating into disposal at sea. The latter dredging/transport system is included so as to make the charts all inclusive but at the same time recognizing that it will not be pursued further since this study addresses only upland disposal with special emphasis on relatively long-distance material movement. These framework charts consider the three functional elements inherent in a dredging/transport system: loading (the actual removal of the material and its placement into a transport mode), transport (the movement of the material from one location to another without relation to distance travelled), and unloading (the discharge or placement of the material into a disposal area, be it intermediate or final, even the actual dumping of the material at sea).



* See Table 3-1 for transport system identification.

Figure 3-1. Long-Distance Transport Systems - Hydraulic Dredge

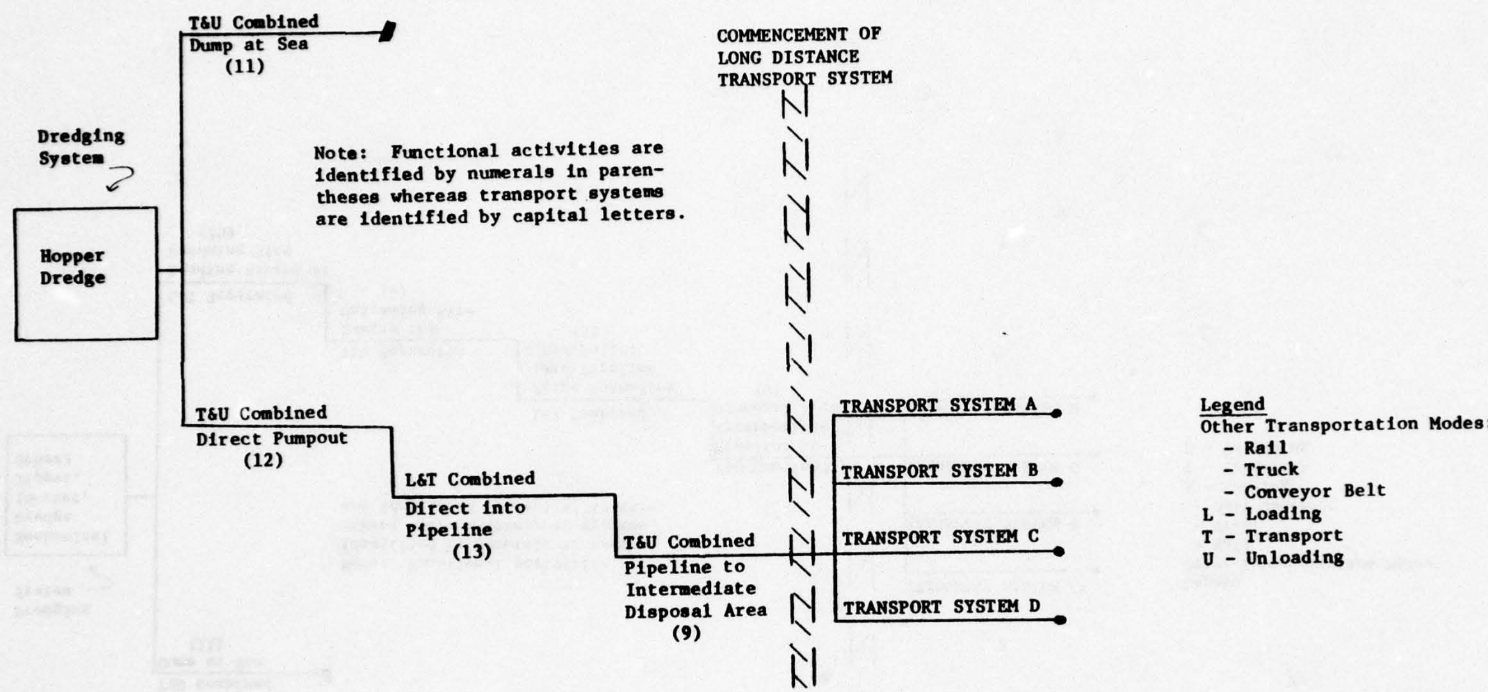


Figure 3-2. Long-Distance Transport Systems - Hopper Dredge

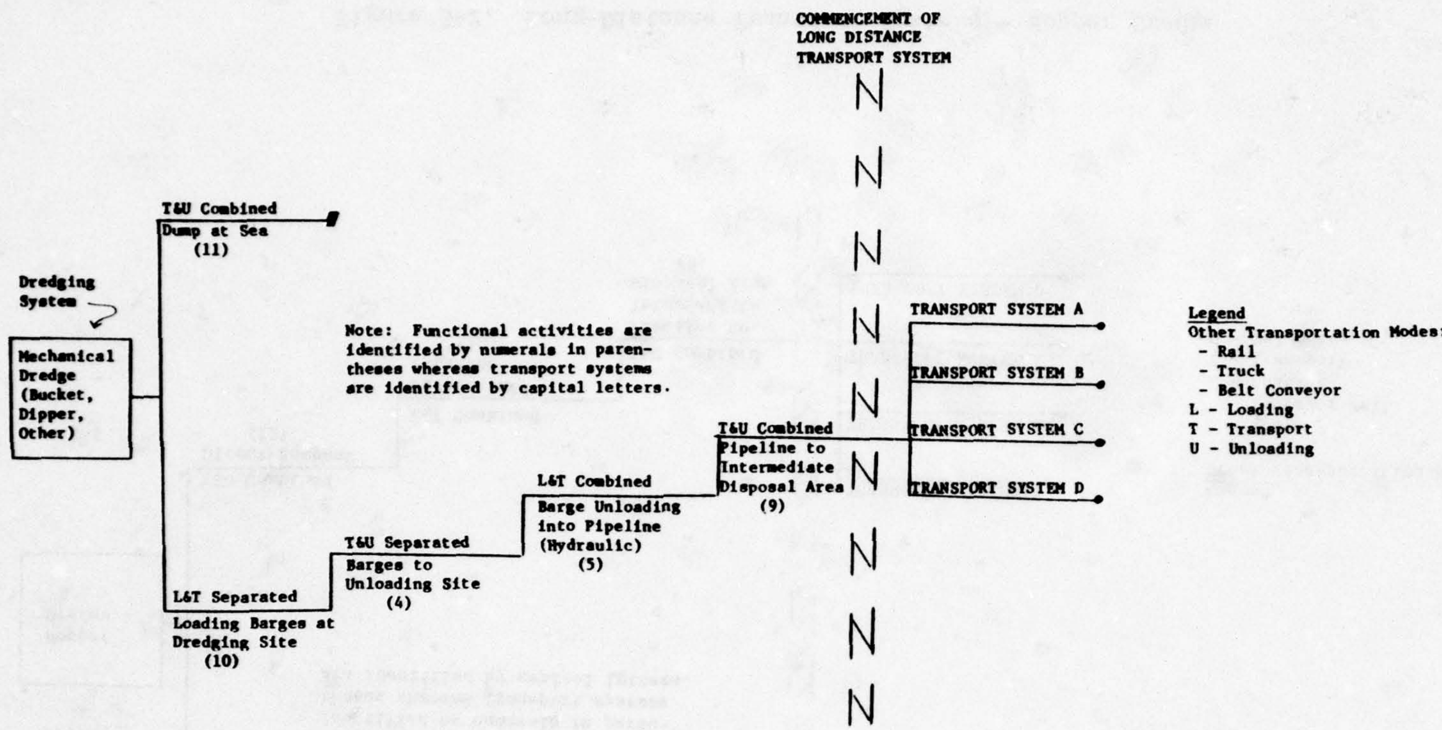


Figure 3-3. Long-Distance Transport Systems - Mechanical Dredge

These charts also show how two of the three functional elements are sometimes combined or separated in the plant or equipment used to perform a particular functional activity. This gives one a better understanding of the dredging/transport systems and the various possibilities which exist. As an example, when a hydraulic pipeline dredge operates in a channel, it loads the material into a pipeline and commences a transport phase; thus, the operation performed represents loading and transporting combined. The next phase continues the movement of the material through the pipeline to the intermediate disposal area and deposits it therein; this operation involving the use of a pipeline obviously represents transporting and unloading combined. On the other hand, when a barge loaded with material is transported to an unloading site for rehandling, there are two distinct and independent operations as well as individual items of plant and equipment required for performing these functions; one is the transport of the material to the unloading site and the other is the actual unloading. Thus, in this example the transporting and unloading operations are separated. Similar analyses could be made for other combinations as depicted on the framework charts.

The charts also show the component functional activities for each of the dredging processes and transport systems. Since these transport systems form the basis for the study, a brief explanation and discussion of one of the charts might give one a better perspective on the system development. Referring to Figure 3-1 and commencing at the box identified as "hydraulic pipeline dredge" at the extreme left side of the figure, the two basic methods of loading the material dredged are shown: either into a pipeline for transport to an intermediate disposal area or into barges for dumping at sea or transport to an unloading site for further transfer of the material. These two units of equipment, the pipeline and the barge, then become the initial transport vehicles associated with the basic dredging operation. If the first method of loading (into pipeline)

is followed, it is to be noted from the chart that the material is transported through this pipeline to an intermediate disposal area and deposited therein. At this point, the long-distance transport commences and is so indicated on the figure. From this point, the intermediate disposal area, the transport system can then proceed in any of three directions through the respective functional activities and develop into four transport systems as shown on Figure 3-1 and as listed in Table 3-1. Similarly, if the second method of loading, identified on the figure as "loading barges at dredging site," is followed, it is noted that the alternatives for the basic dredging operation are to dump at sea or transport the material in the barges to an unloading site where a barge unloader would offload the material into a pipeline and transport it to another intermediate disposal area, different from the one mentioned heretofore. The long-distance transport system for this method commences at this intermediate disposal area and the transport systems available to carry the material to the distant disposal area are identical to those shown in Table 3-1. It is also noted that different transport systems can have several common functional activities.

Figure 3-4 presents in a schematic form the five basic transportation alternatives which are examined in this report. They are:

- Pipeline
- Rail haul
- Barge movement
- Truck haul
- Belt conveyor movement

As shown in the figure, only the pipeline transportation mode involves transporting dredged material in slurry state. All other modes involve the mechanical excavation of dredged material which is considered to be in a relatively dry state.

Table 3-1

Transport Systems and Their Component Functional Activities

Transport System	Sequential Functional Activities
A	(1) Rehandling Unit into Pipeline
	(2) Pipeline to Distant Disposal Area
B	(3) Mechanical Loading into Barges
	(4) Barges to Unloading Site
	(5) Barge Unloading into Pipeline (Hydraulic)
	(2) Pipeline to Distant Disposal Area
C	(3) Mechanical Loading into Barges
	(4) Barges to Unloading Site
	(6) Barge Unloading to Other Transportation Modes
	(7) Other Transportation Modes to Distant Disposal Area
D	(8) Mechanical Loader to Other Transportation Modes
	(7) Other Transportation Modes to Distant Disposal Area

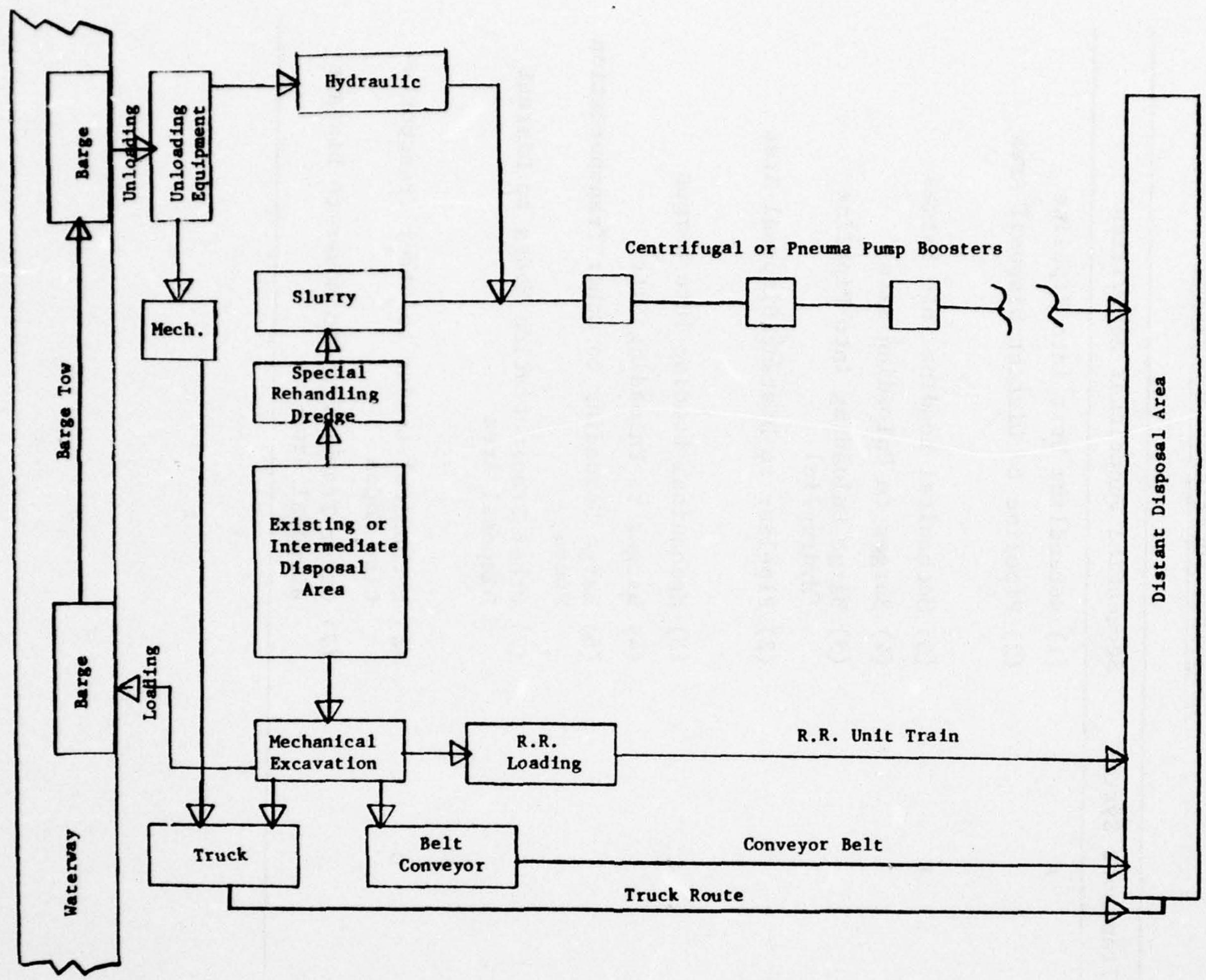


Figure 3-4. Transport Systems - Schematic

PART IV: HYDRAULIC TRANSPORTATION (PIPELINE SLURRY) ANALYSIS

General

The hydraulic movement of a slurry through a pipeline has been used as a transport mode for many types of ores and minerals as well as coal, fertilizers, limestone, and similar materials. Pipeline installations carrying slurries of these types of materials generally traverse long distances, sometimes in excess of 100 miles. Table 4-1 lists several representative slurry pipeline applications for the movement of coal, ores, and minerals. Descriptions of additional applications can be found in The Transportation of Solids in Steel Pipeline[1] and "Slurry Pumps—A Survey."[2]

The most extensive use of hydraulic transport of material, however, is in the dredging field. The major part of all dredging work is accomplished by hydraulic dredging plant. This type of dredging has proved to be a most economical means of mass excavation of material from waterways and adjacent banks and upland areas. Hydraulic dredging operations are usually conducted to improve waterways for navigation, to maintain the improved navigational depths, and to a lesser degree, to obtain construction materials such as sand, shell and gravel, or fill material for land reclamation, highways, airports, or beach protective works. In navigation dredging, the pipeline transport distances usually range up to about 3 miles. For the commercial type land reclamation or fill operation, transport distances are generally longer, with pipeline lengths reaching as much as 15 miles.[3]

Table 4-1

Summary of Major Commercial Slurry Pump Applications[2]

Slurry Material	System	Source of Data	Length (Miles)	Diameter (Inches)	Annual Throughput (Million Tons/Year)	Initial Operation	Type of Pump	Manufacturer	Pump Drive (hp)	Number of Pump Stations	Total Number of Pumps	Flow per Pump (US gpm)	Maximum Discharge Pressure (psi)	Concentration (% by wt)	Maximum Particle Size
Coal	Consolidation	Published	108	10	1.3	1957	Double Acting Duplex Piston	Wilson-Snyder	450	3	9	550	1200	50	14 mesh
	Black Mesa	Bechtel	273	18	4.8	1970	Double Acting Duplex Piston	Wilson-Snyder	1500 1750 1750	4	6 4 3	2100 1400 2100	1080 1785 1165	45-50	14 mesh
Limestone	Calaveras	Bechtel	17	7	1.5	1971	Double Acting Duplex Piston	Continental-Emsco	700	1	2	820	1275	70	28 mesh
	Rugby	Published	57	10	1.7	1964	Double Acting Duplex Piston	Armco Steel	750	1	3	286	2100	50-60	35 mesh
	Trinidad	Published	6	8	0.6	1959	Double Acting Duplex Piston	Wilson-Snyder	180	1	2	310	960	60	48 mesh
	Columbia	Published	17	7	0.4	1944									
Copper Concentrate	Bougainville	Bechtel	17	6	1.0	1972	Vertical Triplex Plunger	Ingersoll-Rand/ Aldrich	700	1	2	482	2000	55-70	65 mesh
	West Irian	Bechtel	69	4	0.3	Under construction	Vertical Triplex Plunger	Ingersoll-Rand/ Aldrich	300	1	2	138	2300	60-65	100 mesh
	KBI Turkey	Published	38	5	1.0	Under construction	Triplex Plunger	Wilson-Snyder	350	1	3	250	2100	45	100 mesh
Magnetite Concentrate	Tasmania	Bechtel	53	9	2.3	1967	Triplex Plunger	Wilson-Snyder	600	1	4	387	2000	55-60	100 mesh
	Waipipi (Land)	Bechtel	4	8	1.0	1971	Centrifugal	Allen Sherman Hoff	250	2	8	2300	400	45	28 mesh
	Waipipi (Offshore)	Bechtel	1.8	12	1.0	1971	Centrifugal	Hazleton/Barrett Haentjens	800	1	6	6450	665	45	28 mesh
Gilsonite	American Gilsonite	Published	72	6	0.4	1957	Double Acting Duplex Plunger	Wilson-Snyder	300	1	3	165	2150	48	4 mesh
Waste Tailings	Japan	Published	44	12	0.6	1968	Double Acting Duplex Piston	Mars	500	1	3	821	710	18	Slimes*
Nickel Refinery Tailings	Western Mining	Bechtel	4.3	4	0.1	1970	Triplex Plunger	Ingersoll-Rand/ Aldrich	30	1	2	98	415	49-60	48 mesh

*00% minus 400 mesh.

The limited transport distances associated with dredging activities, when compared to the distances for ore or mineral slurry transport, do not derive from technical or engineering problems or constraints but rather from the fact that there has not been a compelling need for longer transport distances. In navigation channel dredging operations, disposal areas generally could be found within reasonable distances of the dredging sites. In land reclamation or fill work, the economics of using material dredged from a waterway as against the use of a closer source of upland borrow utilizing customary earth moving equipment has resulted in transport distances of about 15 miles[3] (for which the use of multiple boosters was necessary). Because these longer distance operations were in connection with non-navigation waterway dredging, a more effective control of the slurry to assure a relatively uniform density was possible, and the problems usually associated with multiple booster systems were minimized or eliminated. Under these conditions, multiple booster operations have proved to be practical, and extending the transport distances to about 100 miles should present no unique problems.

Types of Hydraulic Pipeline Systems

There are basically three types of hydraulic pipeline transport systems which can be identified by the type of pumping equipment utilized; namely, positive displacement pumps, centrifugal pumps, and Pneuma* pumps. Of the three systems, the positive displacement pumps operate at the higher pressures. This makes them very attractive for long-distance transport of slurries because fewer booster stations would be required. However, these pumps are extremely sensitive to any variations in maximum particle size of the material to be pumped because valve openings or clearances are minimal.

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* A specific patented trade name pump which operates by means of compressed air.

Consequently, these pumps are incapable of handling material having particle sizes in excess of 1/4 inch. However, they are especially adaptable to applications in the ore or minerals field where the solid material is initially prepared by grinding or otherwise to a fine state, below the critical maximum particle size, prior to being fluidized into a slurry for hydraulic pipeline transport.

Types of Materials

Since materials in disposal areas originate from the bottoms of navigation channels and/or harbor or port complexes, particle sizes are rarely uniform. Gradations may vary from extreme fines such as silts and clays to the coarser grains of sands and sometimes gravels. Also, because of the nature of the use of the waterways to support commercial navigation, foreign matter from consturction and maintenance of harbor facilities such as wharves, piers, etc., and occasional loss of some cargo from barges, etc., find their way into the waterway and are subsequently deposited into the disposal areas at the time the waterway is dredged. This foreign matter could consist of nuts, bolts, spikes, chain, wire rope, cans, and the like. The presence of such material could cause severe problems in the operation of the valve system of positive displacement pumps and unless the material in the disposal area is carefully screened to eliminate such foreign material, and processed, if necessary, to meet the minimum particle size requirements, the use of positive displacement pumps for the hydraulic transport of the dredged material is not practical. This view is shared by the leading manufacturers of these pumps who have advised that under the conditions of the probable existence of foreign material or oversized particles, they would not recommend a positive displacement pump system. Since the investigation of screening or processing of disposal area material prior to transport is beyond the scope of this study, positive displacement pump transport systems are not considered further in this report.

Centrifugal and Pneuma pump systems are currently used for pumping dredged material, and each system is addressed separately on the following pages.

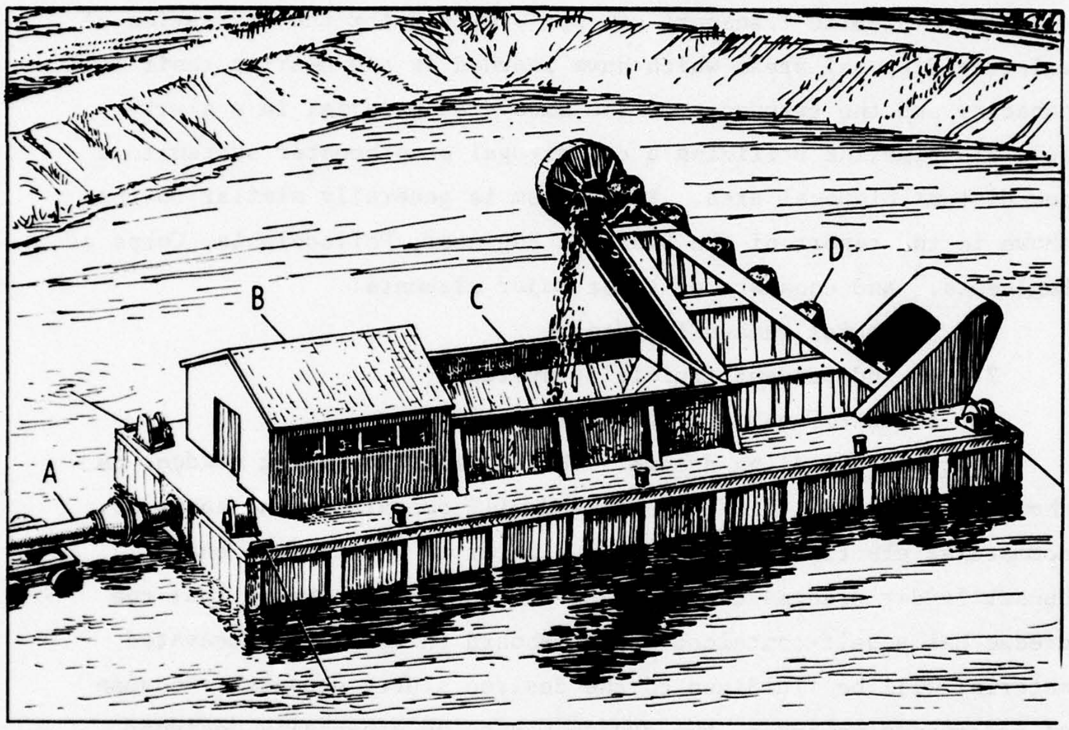
Technical Analysis - Centrifugal Pumping System

Generalized Hydraulic Transport System Concept

The hydraulic transport concept provides for the excavation of existing disposal areas which have reached or are nearing their full capacity and the transport of the excavated material in a slurry form via pipeline utilizing a centrifugal pump booster system to a new distant disposal area. The system is generally similar to that shown in the report of the District Engineer, Philadelphia, Corps of Engineers,[4] and consists of three major elements:

1. A special rehandling dredge
2. An independent fluidizing system
3. A centrifugal pump booster system

Special rehandling dredge. The special rehandling dredge, as shown in Figure 4-1, is portable and will operate on the basis of commercial electric power. It is similar to the endless chain bucket ladder dredges used extensively in Europe, except that the dredge has a self-contained hopper aboard in which the excavated material will be fluidized to the desired slurry density. Because of its unique features, the dredge has to be especially designed. No stock dredge of this type is known to exist. A suitable basin is excavated by dragline in the existing disposal area to provide for flotation and initial movement of the dredge for the dredging operation. The basin is supplied with water for dredge flotation by means of a pump system similar to that at a booster station. This permits the water supply system to be used as a booster station to pump water through the entire length of the system and clear the line in the event of a breakdown of the dredge pumping plant. To



A-DISCHARGE LINE B-HOPPER DECK HOUSE C-HOPPER

D-ENDLESS CHAIN BUCKET PICKUP

Figure 4-1. Special Rehandling Dredge[4]

this end, a valving system is incorporated to bypass the dredge and connect to the pipeline system at a point behind the dredge. Since the dredge is portable, the units and components thereof are assembled at the containment area site.

When the dredge is in operation, the buckets scoop the material from within the disposal area, carry the material up the inclined ladder and, when reaching the upper ladder pivot, dump the material into a hopper abroad the dredge. In this type of operation, the material in the buckets is essentially at the in situ density. The bucket size and speed of the chain are designed for the desired rate of excavation and maximum efficiency, thereby assuring a reasonably fixed rate or constant supply of in situ material being dumped into the hopper. The capacity of the hopper varies between 300-500 cubic yards, depending upon the rate of excavation desired. The hopper serves as a mixing chamber into which water is added at a predetermined rate to fluidize the material to a more or less uniform slurry density. In addition, the hopper is provided with a mechanical mixing device to insure proper mixing of the dredged material with the fluidizing water. The hopper also serves as the receptacle from which a constant supply of the slurry can be fed to the centrifugal pumping system aboard the dredge which consists of two pumps in series.

The rehandling system is designed to satisfy the production requirements of a specific disposal area. In general, the production capacity for the optimum percent operating time per year should be slightly greater than the annual quantities dredged from the navigation channels.

Independent fluidizing system. The independent fluidizing system consists of a water supply pumping system with an intake from the closest water source (generally this is the nearby navigation project waterway) and a pipeline leading to the disposal area basin. This pumping system provides water to the basin at a rate sufficient to maintain flotation of the dredge as material is removed and the

basin enlarged, plus the amount of water necessary to fluidize the material excavated to the slurry density desired. The material in the hoppers is fluidized to a relatively uniform slurry density by means of a controlled water intake in the dredge hull with an assist from an auxiliary jet pump and mechanical mixing device to maintain the material in suspension. The slurry in the hopper will lead through a collection line to the suction intake at the primary pumping system aboard the dredge.

Centrifugal pump booster system. The centrifugal pump booster system consists of a series of identical booster stations generally spaced uniformly from the dredge to the distant disposal area. At each station the pumping system has two, essentially similar pumps, arranged in series. However, if deemed necessary to optimize reliability of operation, an auxiliary spare pump and motor with all pertinent piping, valves and connections can be provided for emergency use in event of a major breakdown in the primary equipment. The two pumps together will have the capability of developing a total discharge head of 500 feet. The 500 feet head was selected after discussion with several of the leading designers and manufacturers of centrifugal pumps for dredging applications.* It was their general opinion that suitable centrifugal pump equipment is available or could be satisfactorily designed to meet the following requirements and conditions:

1. Develop a total head of slurry of 500 feet and corresponding discharge pressures.

2. The slurry to be pumped will have a maximum density of 1500 grams per liter.

3. The material in the slurry will be of the less abrasive maintenance types such as the muds, silts, and unconsolidated and uncompacted clays.

4. There are essentially no suction problems or limitations.

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* Based on discussions with representatives of Morris Pump Company and Ellicott Machine Company.

Thus the pumps will each develop discharge heads of 250 feet with pressures equivalent to heads of slurry of 250 feet and 500 feet, respectively, for the first and second pump in the series. The booster system is automated so that booster stations would be operated by remote control from the rehandling dredge. It is contemplated that all booster stations be land based and, as such, be supported on a concrete slab within a corrugated sheet metal building of minimum size and cost. The entire installation is enclosed with a cyclone fence as a safety precaution and to provide some degree of security.

The stations are electrically operated with the power obtained from commercial sources. At each station, sealing water for the booster pumps is provided by a gland sealing water pump. Some of the possible sources of water intake for this purpose are subsurface (wells), rivers, and other natural bodies of water, with the selection of a particular source at a specific location depending on availability and costs. In some instances it may be necessary to consider an auxiliary water delivery line commencing at the dredge and running alongside the entire length of the slurry pipeline from which sealing water could be tapped off at each booster station.

A 10-percent reduction in the computed theoretical booster station spacing is provided in the design. This is considered a reasonable contingency or safety factor. It also provides for moderate rises (i.e., 40-60 feet) in elevation along the route from the existing disposal area to the distant one. Large differences in elevation are not anticipated. However, in those special cases where this may occur, the number of booster stations could be increased by an additional one for every 500-foot increase or multiple thereof in static head.

As indicated, it is contemplated that the power source be electricity. Generally, this type of power is or could readily be made available along the pipeline route. The motors would be

alternating current and be of variable speed. Although the excavating unit of the rehandling dredge and the fluidizing system should provide a feed of uniform slurry density to the pumps, occasional variations or fluctuations can be expected. In order to have the flexibility necessary to adjust for these variations and to balance the system, variable speed motors are recommended. All booster stations have the necessary electrical devices such as circuit breakers, transformers (if available voltage is not compatible with the motors), switchboard, and automation equipment.

The system is automated to the maximum extent feasible with primary control being at the rehandling dredge. All booster stations are operated by remote control from the dredge and thus the booster stations have no basic requirement for operating personnel. However, it is considered prudent from an operations safety and security standpoint to provide for a minimum patrol of the booster stations so that routine visual inspections of all plant and equipment are made on a periodic basis.

Detailed Theoretical Design of Centrifugal Pumping Systems for the Transport of Dredged Material Inland

The detailed design of a hydraulic transport system as described in general terms above involves the examination of several principal variables and design parameters. It requires that the significance and effects of the variables on the design of the system be recognized and that realistic values be established and assigned to the design parameters. There are basically three principal variables which affect the design of the system:

1. The density of the material in the disposal area.
2. The density of the slurry to be pumped.
3. The annual quantity of in situ material to be transported.

There are three major design parameters which require detailed review and evaluation before values can be assigned.

1. Critical or minimum velocity of flow of the slurry in the pipeline.

2. Coefficient of friction to determine head loss.

3. Total developed head for the pump.

These variables and design parameters are discussed below.

● The density* of the material in the disposal areas. This variable is a major factor in determining the volume of slurry of a specified density produced by fluidizing a unit volume of in situ material in the containment area. In situ densities could vary considerably from one disposal area to another depending on the type and characteristics of the material dredged from the navigation channel and deposited in the disposal area. Representative samples of the existing disposal area material are required to establish the average in situ density of the disposal area material.

● The density** of the slurry to be pumped. This is another important variable as it directly affects the volume of material being removed *from the disposal area.* Pipeline slurry density design requirements vary significantly based on the method of feed to the pump, the type and gradation of the material, and pump characteristics and speed of operation. Selection of slurry densities for design purposes would usually be based on experience for the particular type of material and its compatability with the pump characteristics as well as the effectiveness of the control exercised over the dredging and fluidization operations to assure optimal and constant feed of the material at the design slurry density.

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* The density of the material in the disposal area is defined as the bulk density of the in situ material in a saturated state and is expressed in grams per liter. This definition applies throughout this report.

** The density of the slurry is defined as the bulk density of the mixture being pumped and is expressed in grams per liter. This definition applies throughout this report.

• The annual quantity of in situ material to be transported. This variable affects directly the size of the transport system (particularly the diameter of the pipeline), the horsepower requirements for the prime movers, and the size of the booster pumps. The pipeline diameter affects friction head losses, booster station spacing, and critical velocities, all of which impact significantly on system costs.

• Critical or minimum velocity of flow of the slurry in the pipeline. This design parameter is generally defined as that average velocity below which solid particles suspended in the slurry will deposit on the bottom of the pipe. The most economical design generally results when the average pipeline velocity is near the critical velocity. This occurs because friction head losses for flow in pipelines increase almost as the square of the velocity, and horsepower requirements increase in direct proportion to increases in friction losses. As a result, higher velocities require substantially greater power. Empirical formulas have been developed from which critical velocity determinations can be made for different solids concentration and particle size. One such formula, developed by Durand and Condolis,[5] considered worthy of particular mention is based on extensive field experiments and tests. The critical velocity is usually determined by laboratory analysis, practical experience, or empirical formula.

• Total developed head for pump. This parameter is primarily a function of the characteristics and construction of the particular type of centrifugal pump, especially the pump packing and gland seals and the abrasiveness of the type of material in the slurry.

Pipeline system design methodology and data. The design of a long-distance hydraulic pipeline transport system for any set or combination of the variable conditions described above (the density of the material in the disposal area, the density of the slurry to be pumped, and the annual quantity of in situ material to be

transported), requires that a series of general curves, graphs, and tables be developed covering the usual range of these variables. From this range, the values for any given set of conditions can be extracted. To derive these data requires that realistic values be assigned for the three major parameters, critical velocity, coefficient of friction, and total developed head for the pump. The range of the possible values for the two most important parameters, the critical velocity and the coefficient of friction, and their effect on system design and costs are significant. The values of the critical velocity and/or coefficient of friction parameters are affected to varying degrees by many factors including the type and characteristics of the material being pumped, the specific gravity of the material, the slurry density, the particle sizes and gradation curves for the material, and the diameter and relative roughness of the pipe. Since the type and characteristics of the material to be excavated could differ greatly from one disposal area to another, the value of the parameters will also differ depending on the particular disposal area. For this reason, the study methodology is based on establishing a range of design data which depict the approximate upper and lower limits within which one could expect the results for different sites and sets of conditions to fall.

The lower limit is designated as the "base" condition which reflects the most ideal or favorable conditions for a long-distance hydraulic transport system. The base condition assumes a relatively low critical velocity value that would be associated with the extremely small size particles of the light muds and silts, and assumes a relatively low coefficient of friction factor. The remainder of this sub-section focuses on deriving design data and subsequent cost data for a hydraulic transport system under base conditions.

In order to assess less favorable design conditions, a detailed sensitivity analysis was performed to analyze the effects of variations

in these design parameters on system costs. The results of the sensitivity analysis are presented at the end of this section of the report.

The development of these minimum value general curves, graphs, and tables is based upon the following step-by-step sequential procedure:

1. Establish the base value for critical velocity.

2. Establish the base value for the coefficient of friction.

3. Establish the base value for total developed head for the pump.

4. Develop curves which depict the ratio of the volume of solids in one liter of in situ material to the volume of solids in one liter of slurry for variable in situ and slurry densities.

5. Develop curves which relate the required quantity of flow or discharge of slurry to the quantity of annual excavation requirements for variable disposal area and slurry densities.

6. Develop curves which give the modified base values of the critical velocity parameter resulting from changes in pipe diameters.

7. Develop curves which give the quantity of flow or discharge of slurry at the base critical velocity for different size pipes.

8. Develop curves which give the booster station spacing for different diameter pipeline systems under conditions of flow at their respective base critical velocities.

9. Develop curves which give the brake horsepower requirements per pump at a booster station for variable slurry densities and quantities of flow or discharge.

10. Develop curves which give the water requirements in the disposal area to maintain flotation of dredge and to fluidize the dredged material for variable disposal area and slurry densities.

The establishment of the parameter values and the development of the several curves including the basis for the derivation of the engineering data are fully discussed below and are referenced in the same order as the items of the above list for the step-by-step procedure. The following symbols and definitions apply to the equations used in the development of the curves:

d_{abs} = Absolute density of solid material - 2600 grams per liter (dry without voids)

d_a = Bulk density of disposal area material - grams per liter (in saturated state)

d_s = Bulk density of slurry - grams per liter

d_w = Density of water - 1000 grams per liter or 62.4 pounds per cubic foot

V_c = Critical velocity - feet per second

D = Diameter of pipe - feet

V_s = Velocity of slurry in pipeline - feet per second

Q_s = Slurry discharge rate - cubic feet per second

L = Length of pipeline between booster station - feet

BHP = Brake horsepower

H_t = Total dynamic head - feet of slurry

g = Acceleration of gravity - 32.2 feet per second^2

f = Friction factor

R = Ratio of the volume of solids in one liter of in situ material to the volume of solids in one liter of slurry

P = Disposal area excavation rate - cubic yards per year

- Step 1 - Critical velocity. A base critical velocity of 9.0 feet per second for a 12-inch diameter pipe has been assumed as being realistic for the type material contemplated to be transported under the base conditions. The material to be pumped would be of the extremely fine, small particle size muds and silts usually associated with those navigation projects where the maintenance material dredged is of the light fluffy type. It is recognized that the critical

velocities will be slightly higher where the material in disposal areas contains some quantities of larger size particles such as increasing proportions of fine to medium sands. However, it is not expected that any disposal areas containing significant amounts of material in the particle size range of medium to coarse sands and above would be excavated for purposes of long-distance transport since such material would be in demand for beneficial or production use closer to the existing disposal area.

• Step 2 - Coefficient of friction. The value of the coefficient of friction for use in the Darcy-Weisbach formula (shown under Step 8) is assumed as 0.028 for the base value. This is considered appropriate for the type material for the base curve condition and is recommended by a recognized authority in the dredging field.[6]

• Step 3 - Total developed head. The figure to be assumed for the total head developed by the pump should be compatible with the maximum pressure which can be tolerated by the pump seals for the type material to be pumped. Generally, for dredged material, centrifugal pumps are limited to a maximum pressure equivalent to a head of about 500 feet. This latter figure has been assumed in the subsequent data development as being equally applicable to the base curve and other conditions.

• Step 4 - Ratio of disposal area solids to slurry solids. Figure 4-2 provides the ratio of the volume of solids in one liter of in situ material to the volume of solids in one liter of slurry for variable disposal area in situ densities and slurry densities. For any set of density conditions, it gives the number of unit volumes of slurry required to transport one unit volume of disposal area material. This chart is based on the formula:

$$\text{Ratio} = \frac{d_a - d_w}{d_s - d_w} = R$$

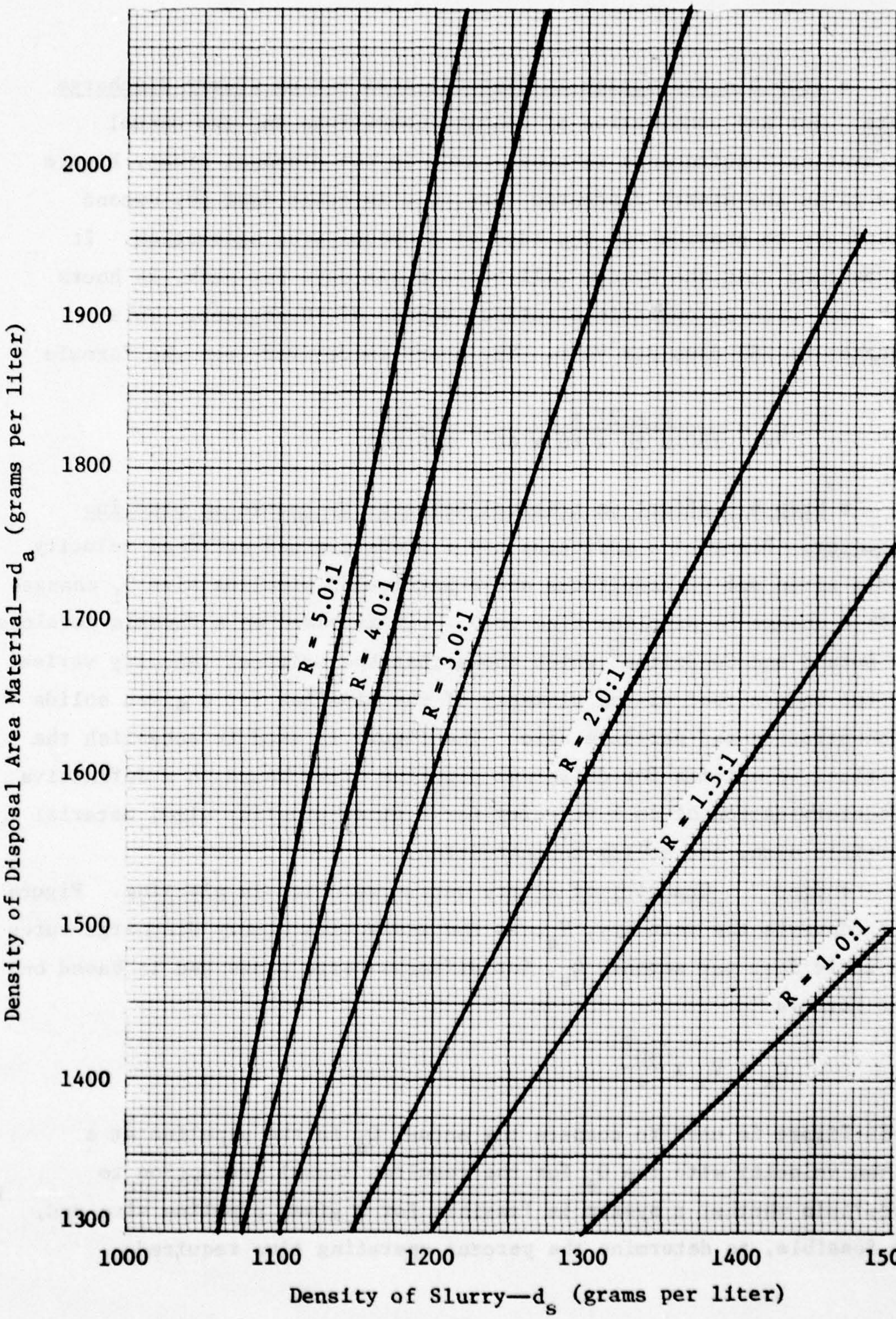

Figure 4-2. Ratio R for Variable Disposal Area In Situ and Slurry Densities

• Step 5 - Production in disposal area versus slurry discharge rate. For any combination of density conditions and the annual excavation requirements in cubic yards in the disposal areas, Figure 4-3 gives the slurry discharge rate, Q_s, in cubic feet per second necessary to provide for the rate of disposal area excavation. It is assumed that the system will operate six days per week, 24 hours per day, with an operational effectiveness of 90 percent. This equates to 280 days per year. The chart is derived from the formula

$$Q_s = \frac{P \times 27 \times R}{280 \times 24 \times 60 \times 60} = \frac{P \times R}{896{,}000}$$

• Step 6 - Effect on critical velocity by change in pipeline diameter. Figure 4-4 indicates how a predetermined critical velocity for a given set of conditions and a particular pipeline size D_1 changes with a change in pipeline size to D_2. It is based on a formula developed by Durand and Condolios[5] which shows that the critical velocity varies as the square root of the diameter of the pipeline for a given solids concentration and particle size. The figure is used to establish the critical velocities for different pipeline sizes based on a definitive predetermination of such velocity for a given pipeline size, material particle size, and solids concentration.

• Step 7 - Quantity of slurry versus velocity in pipeline. Figure 4-5 converts the velocity, V_s, to the respective slurry discharge rates in cubic feet per second, Q_s, for different size pipes and is based on the formula

$$Q_s = V_s \times \frac{\pi D^2}{4}$$

This figure is used to compare the actual Q_s in the pipeline at a given velocity with the Q_s for the required annual production to ascertain whether a system is feasible for a given pipeline size and, if feasible, to determine the percent operating time required.

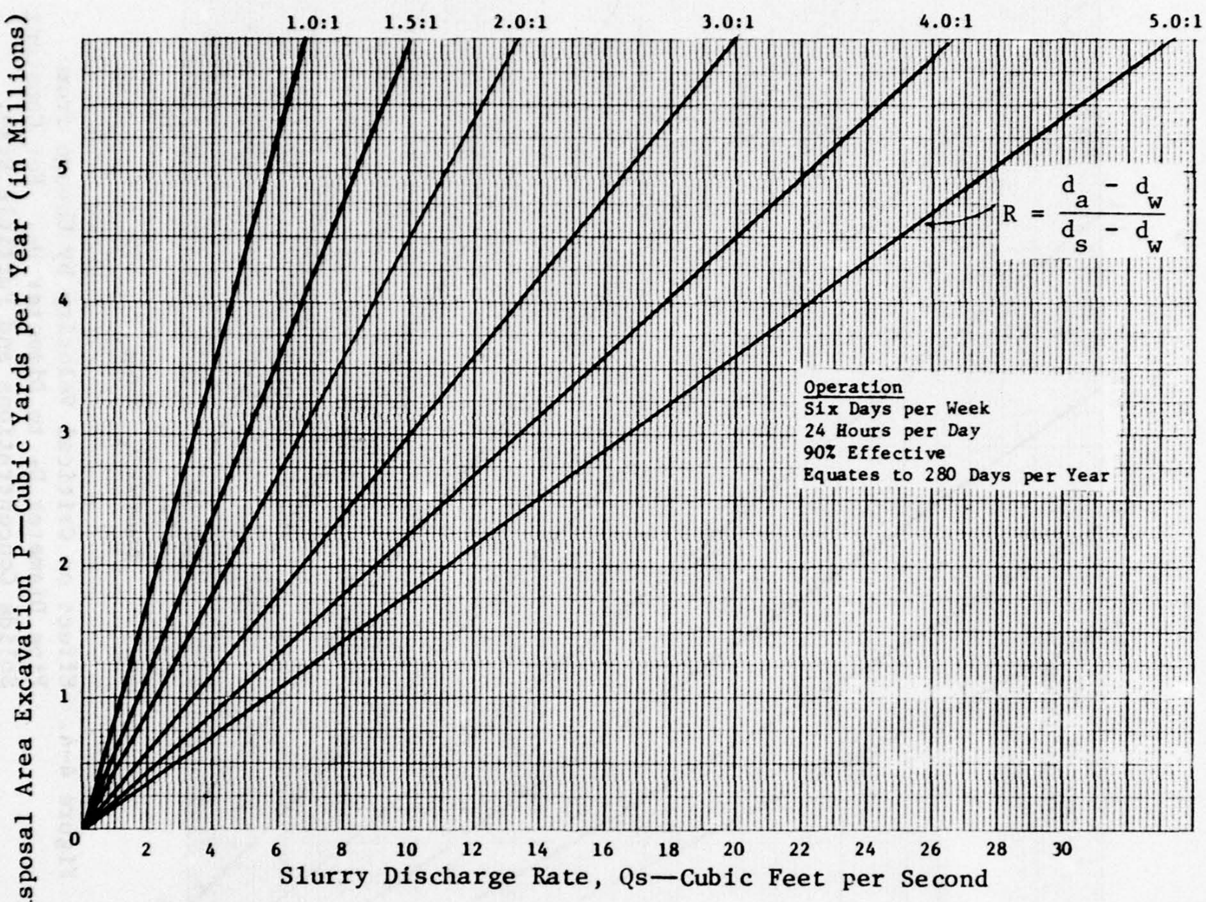

Figure 4-3. Disposal Area Excavation vs. Slurry Discharge Rate

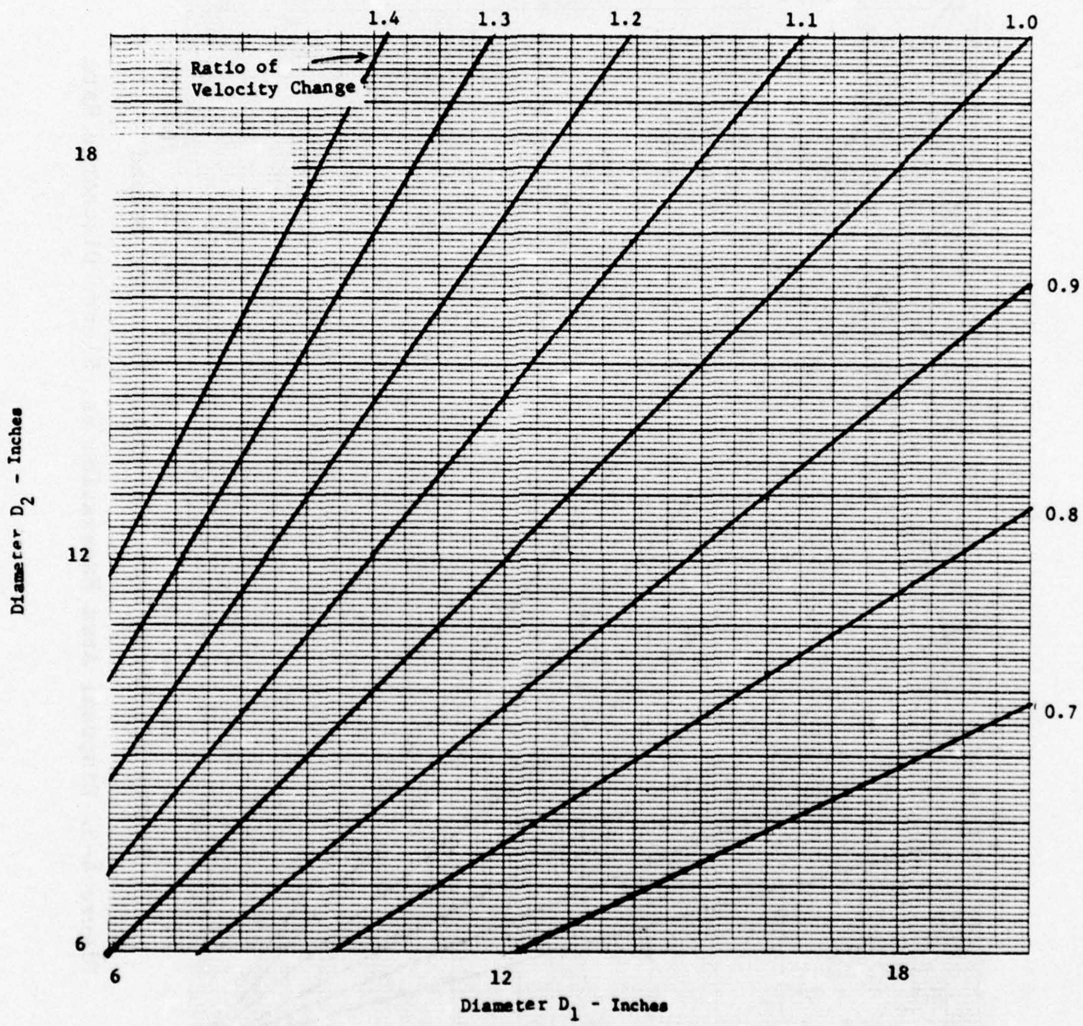

Figure 4-4. Effect on Critical Velocity by Change from Pipe Diameter D_1 to Diameter D_2. For Constant Solids Concentrations and Particle Size.

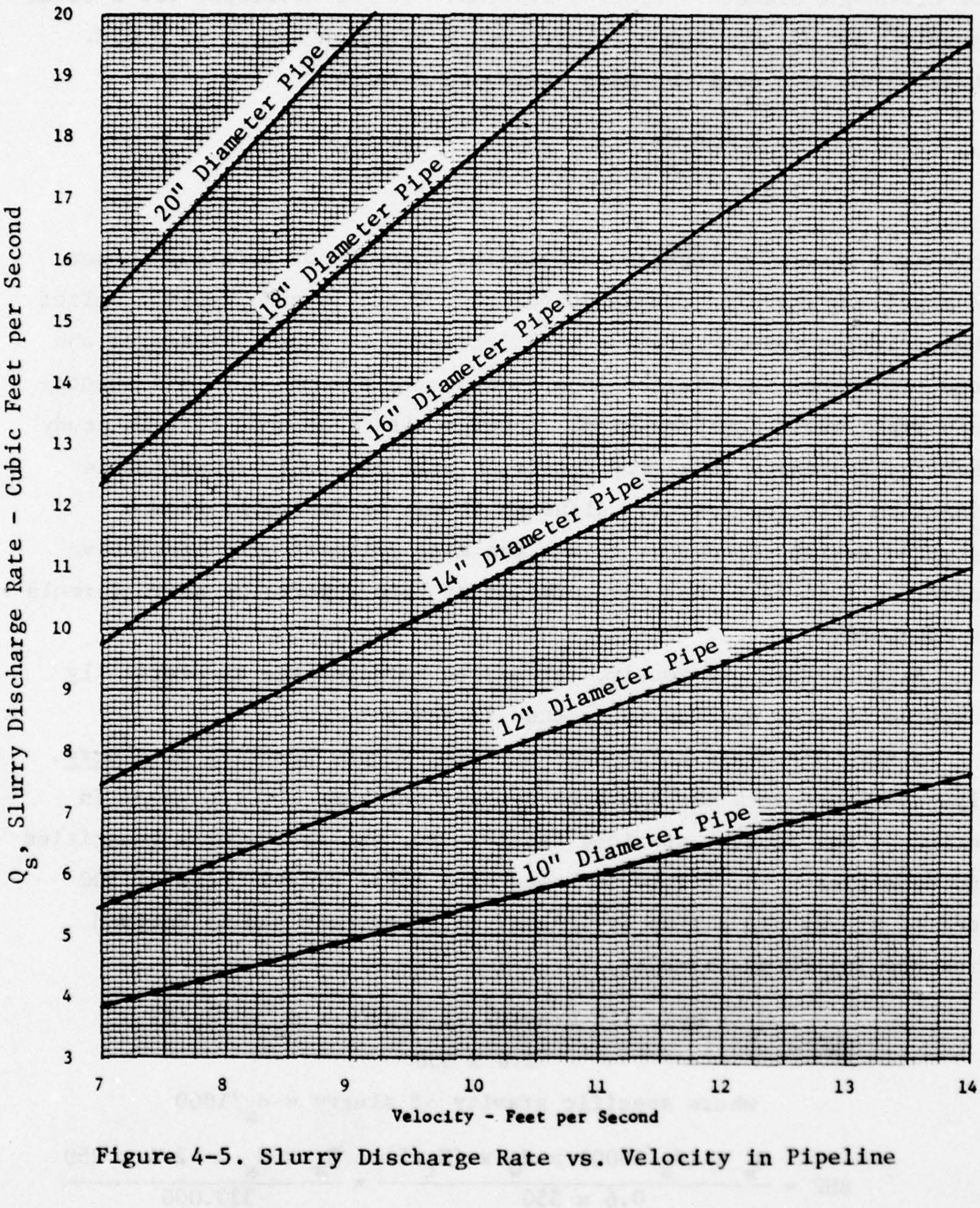

Figure 4-5. Slurry Discharge Rate vs. Velocity in Pipeline

• Step 8 - Booster station spacing versus velocity in pipeline. Figure 4-6 provides the theoretical booster station spacing required for different diameter pipeline systems. It was developed for a total dynamic head of 500 feet of slurry and a friction factor of 0.028. It is based on a modified Darcy-Weisbach formula:[6]

$$L = \frac{H_t \times D \times 2g}{f \times V_s^{1.75}}$$

This is a generally accepted simplified formula for friction losses in pipelines carrying dredged material. There is some general belief that friction losses increase with increases in slurry densities and some refinement in friction-loss formulas to account for this phenomenon might merit consideration. However, it is assumed in this study that the increases in slurry densities will have only a negligible effect on friction losses. Although it may be desirable from a detailed design standpoint to use the most critical or conservative formula, it is felt that for purposes of this report the above formula is adequate.

As indicated previously, for design purposes the theoretically computed booster spacing is reduced 10 percent.

• Step 9 - Brake horsepower per pump versus quantity of slurry. Figure 4-7 presents the brake horsepower per pump for two pumps in series at the booster stations required for variable slurry quantities and densities. The figure is based on a total dynamic head of 500 feet of slurry and a pump efficiency of 60 percent and is derived from the following formula:

$$BHP = \frac{Q_s \times \text{specific gravity of slurry} \times d_w \times (H_t/2)}{0.6 \times 550}$$

where specific gravity of slurry = $d_s/1000$

$$BHP = \frac{Q_s \times (d_s/1000) \times d_w \times (H_t/2)}{0.6 \times 550} = \frac{Q_s \times d_s \times 62.4 \times 250}{330{,}000}$$

$$BHP = .047272\ Q_s d_s$$

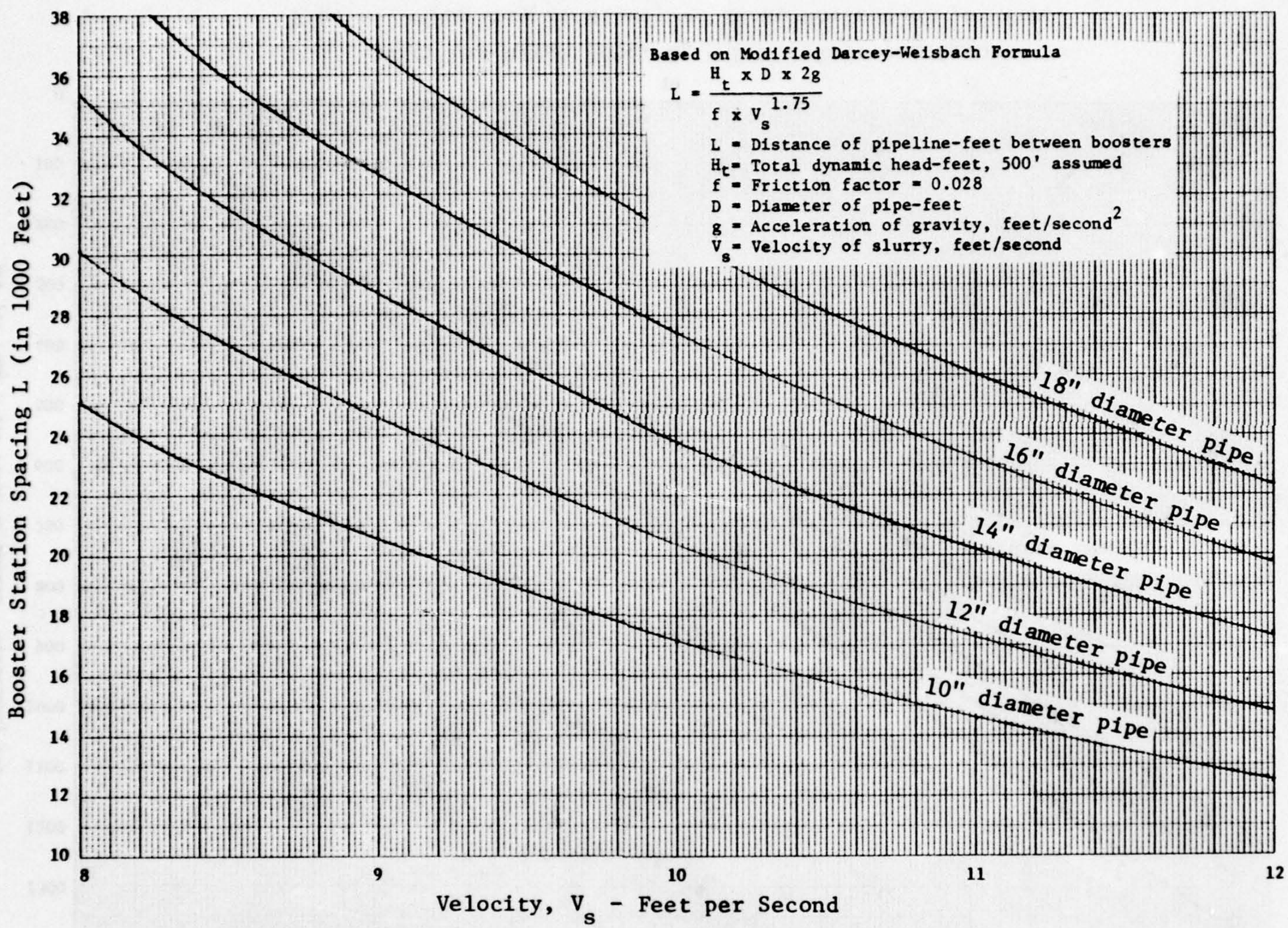

Figure 4-6. Booster Station Spacing vs Velocity in Pipeline

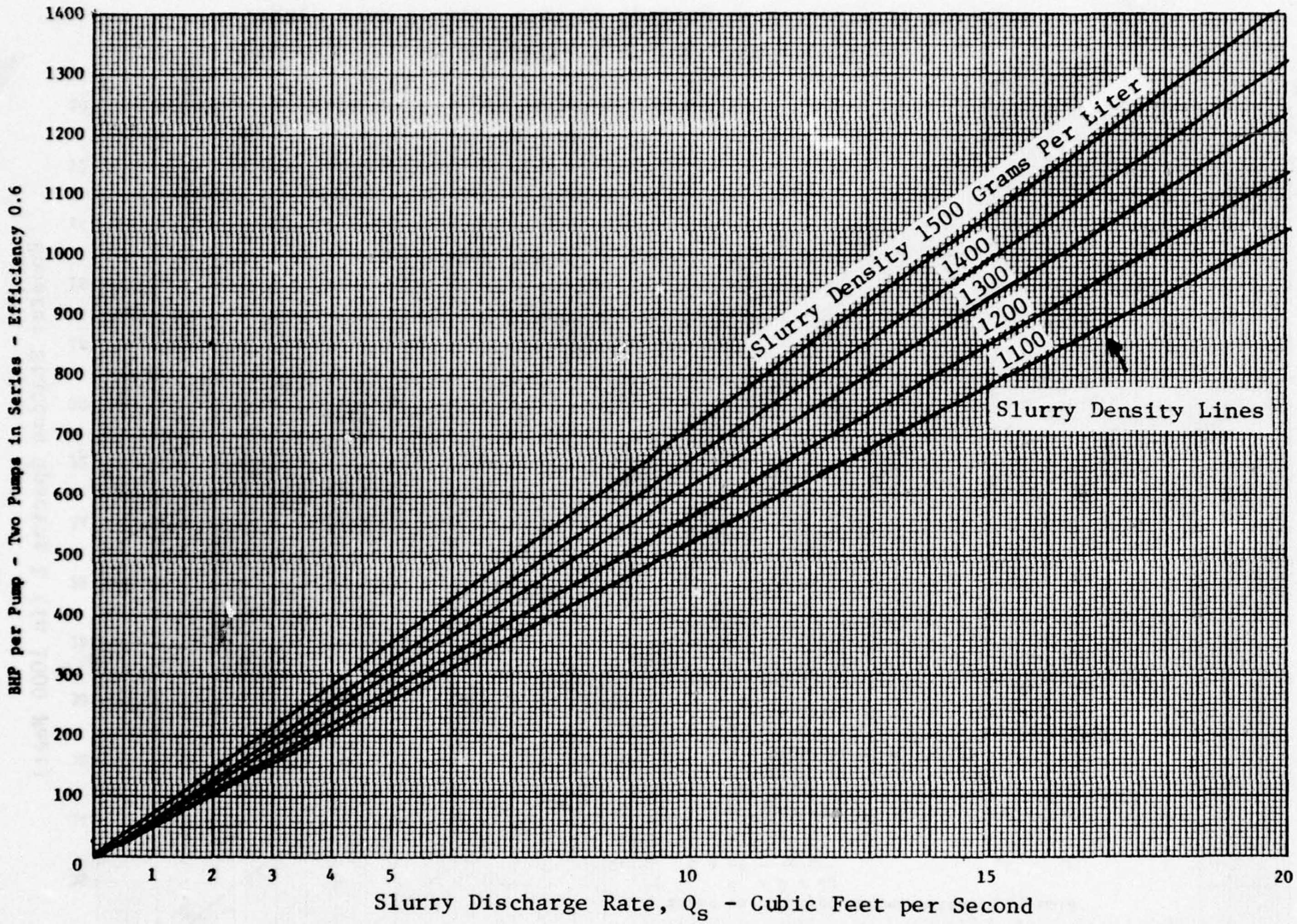

Fig. 4-7—Quantity of Slurry vs Brake Horsepower per Pump

This figure is used to determine the power requirements for different systems.

• Step 10 - Water requirements for slurry and flotation. Figure 4-8 gives the water requirements necessary to fluidize the dredged material to a particular slurry density and to provide for flotation of the dredge as material is excavated from the disposal area. The respective water requirements are shown in cubic feet per second and must be combined to give total requirements. The pumping system for furnishing these water requirements has intentionally been made similar to the booster station system, thereby furnishing a standby capacity to clear the entire system in the event of a shutdown of the dredge's pumping plant. This would be accomplished by a system of valves which would divert the water being pumped to the disposal area to the pipeline behind the dredge pumps. The formulas used to develop this graph are as follows:

For slurry requirements:*

$$\text{Water requirement} = Q_s \times \left(\frac{d_{abs} - d_s}{d_{abs} - d_w}\right)$$

$$\text{Water requirement} = Q_s \times \left(\frac{2600 - d_s}{2600 - 1000}\right) = \left(\frac{2600 - d_s}{1600}\right) Q_s$$

For flotation requirements:

$$\text{Water requirement} = Q_s \times \left(\frac{d_s - d_w}{d_a - d_w}\right)$$

$$= Q_s \left(\frac{d_s - 1000}{d_a - 1000}\right) = \frac{Q_s}{R}$$

Utilizing these sets of graphs, the required base system configuration for any set of variable conditions can be developed. A definitive example of the use of the data on these figures to arrive at a base system configuration for a particular set of conditions is provided in a later subsection.

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* In situ material is assumed to be in a dry state.

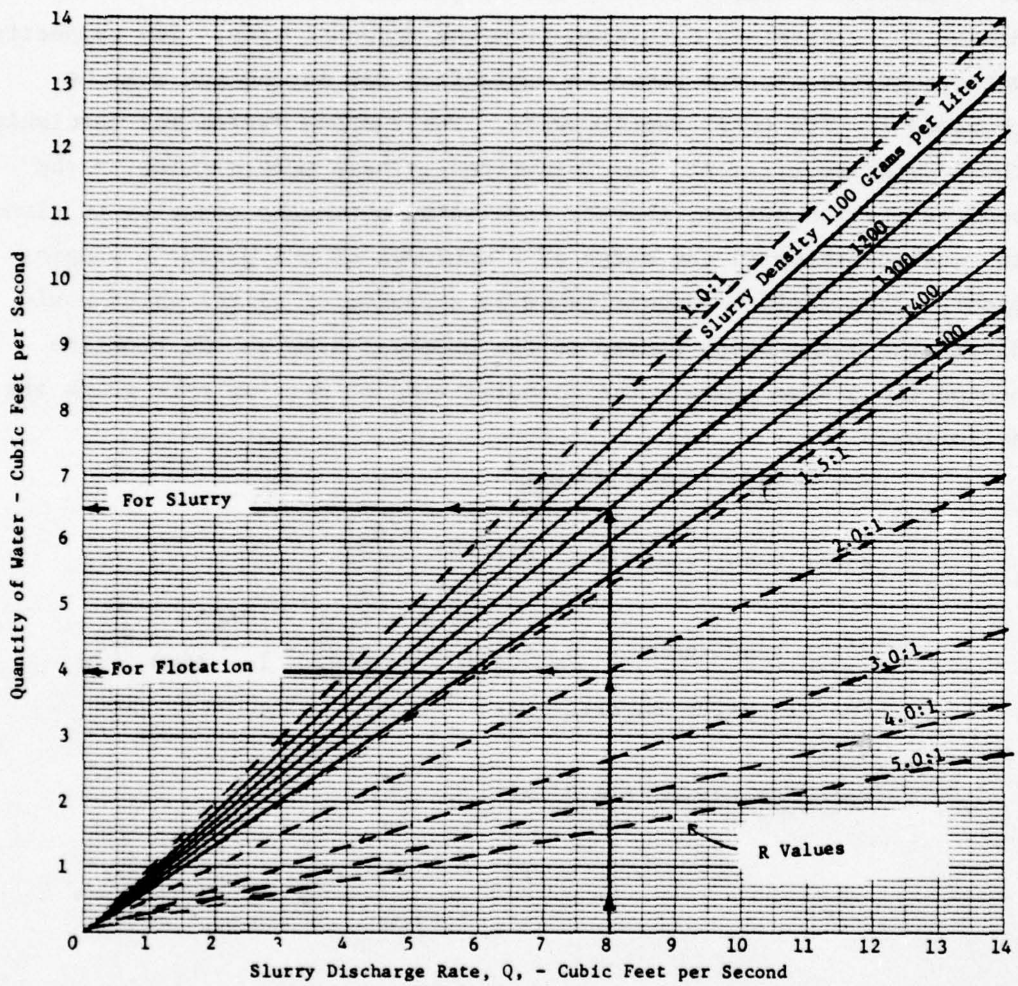

Figure 4-8. Water Requirements for Slurry and Flotation

Cost Analysis - Centrifugal Pumping System

Cost Derivation

The design data developed in the prior section above have been derived on the basis of the most favorable design conditions. Accordingly, all cost data developed from these data will represent optimistic costs for hydraulic transportation. Based on these data a series of cost curves have been developed to provide the necessary cost data associated with any particular pipeline system designed from the previous charts. The cost data have been developed on the basis that in actual practice any long-distance hydraulic transport system would be constructed by the Government and would be contractor rather than Government operated. Individual contracts would be limited to one- or two-year periods. The rationale for this assumption stems from the following factors.

- The plan of operation for re-excavating existing disposal areas is to partition these areas into two or four parts, whichever is more practical, depending on its size, and to excavate each part in sequence. When the dredging is completed in one section, that section becomes available for receipt of material removed from the channel maintenance dredging operations. The dredge meanwhile has moved into and is operating in the next section. This sequential procedure is continued until the end of the contract period. Each successive contract will operate on a similar basis.

- The large initial investment required in plant, equipment and installation of the system would not make the work attractive to private contractors. Since the duration of the operations would be long term, the various cost factors could be expected to fluctuate greatly, making realistic definitive cost estimating over an extended period almost impossible.

- A Government-owned facility with contractor operation will assure the least cost because adequate bidding competition will be maintained, particularly if the contract for operation of the facility is limited to one- or two-year periods.

• The operation of the system by contract is in line with the Government's general policy of contracting out work whenever reasonable prices can be obtained.

The following figures and tables provide the basis for the cost derivations for each of the major elements of the pumping system. It is to be noted that real estate and rights of way costs are not included in any of the cost estimates for hydraulic pipeline transport systems. (See page 4-46 for further discussion.)

Booster costs for variable horsepower versus booster spacing. Figure 4-9 presents the costs for the booster stations for variable pump horsepower and booster station spacing. This figure and Figure 4-12 include a cost adjustment for the design concept of reducing the booster spacing by 10 percent. The cost data cover the pumps and electric motors, reduction gears, control equipment, foundation, housing, provisions for sealing water (wells and necessary pumps), installation, allowances for maintenance and repair, lay up costs, insurance, and such other miscellaneous costs as applicable.* All first costs are converted to annual amounts on a capital recovery basis for a 20-year life at 7-percent interest. The data in Figure 4-9 are derived from the following formula:

$$\begin{array}{l}\text{Booster system}\\ \text{cost per year}\\ \text{per 1000 feet}\end{array} = \frac{\text{Annual cost per booster pump x 2}}{\text{0.9 x booster spacing (1000 ft)}}$$

Note: the 0.9 factor in the denominater represents the adjustment to provide for the 10% reduction in booster station spacing.

The annual cost per booster pump for variable horsepower is shown in Table 4-2.

Annual pipeline cost per 1000 feet. Table 4-3 provides the costs for different pipeline sizes for variable years of life. The cost data are based on average procurement costs for ordinary dredge pipe, 5/16 inch thick and in lengths of 40 feet. The theoretical life of pipe is a variable ranging from one to 20 years, the latter being the maximum life of the transport system. The

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* First costs including ancillary items such as control equipment, power hookups are based upon general estimates for typical equipment of this type.

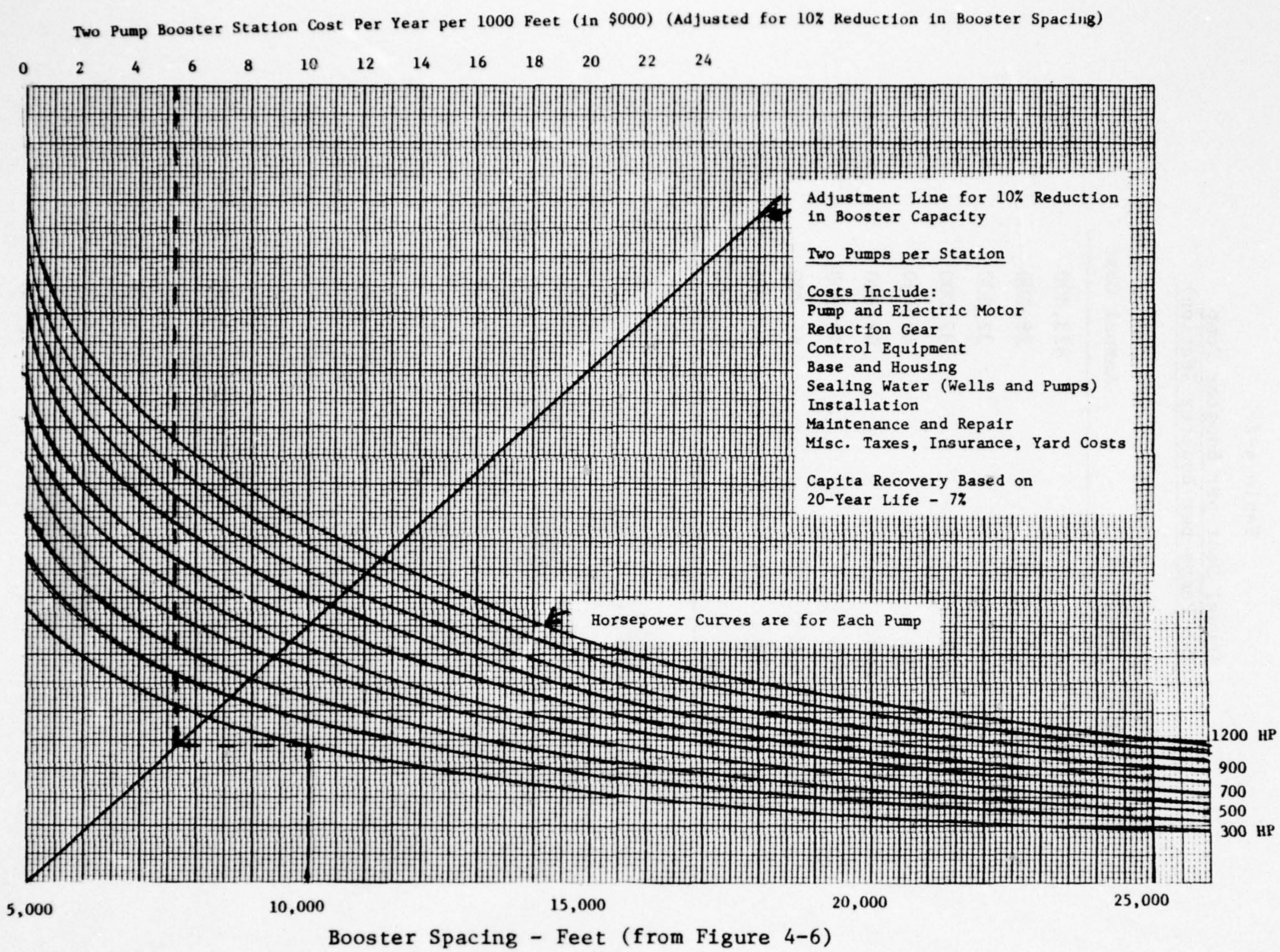

Figure 4-9. Booster Costs for Variable Horsepower vs. Booster Spacing

Table 4-2

Annual Cost per Booster Pump
(Two Pumps per Booster Station)

Horsepower	Annual Cost
300	$23,800
400	28,200
500	32,600
600	37,000
700	41,400
800	45,800
900	50,200
1000	54,700
1100	59,100
1200	63,500

Table 4-3

Annual Pipeline Cost per 1000 Feet*

(In Dollars)

Effective Life-Years	Pipeline Size - Inches						
	8	10	12	14	16	18	20
1	15,000	18,200	21,900	26,700	32,100	37,500	46,000
2	7,700	9,400	11,300	13,800	16,600	19,400	23,800
3	5,500	6,600	8,000	9,700	11,700	13,600	16,800
4	4,100	5,000	6,100	7,400	8,900	10,300	12,700
5	3,400	4,100	5,000	6,100	7,300	8,500	10,500
6	3,200	3,900	4,700	5,700	6,800	7,900	9,800
7	2,700	3,200	3,900	4,700	5,700	6,600	8,200
8	2,500	3,100	3,700	4,500	5,400	6,300	7,800
9	2,400	3,000	3,600	4,300	5,200	6,100	7,500
10	2,000	2,400	2,900	3,600	4,300	5,000	6,100
11	1,900	2,400	2,900	3,500	4,200	4,900	6,000
12	1,900	2,300	2,800	3,400	4,100	4,800	5,900
13	1,800	2,300	2,700	3,300	4,000	4,700	5,700
14	1,800	2,200	2,700	3,300	3,900	4,600	5,600
15	1,800	2,200	2,600	3,200	3,900	4,500	5,500
16	1,700	2,100	2,600	3,200	3,800	4,400	5,400
17	1,700	2,100	2,500	3,100	3,700	4,400	5,300
18	1,700	2,100	2,500	3,100	3,700	4,300	5,300
19	1,700	2,000	2,500	3,000	3,600	4,200	5,200
20	1,300	1,600	1,900	2,400	2,800	3,300	4,100

*Includes installation.

theoretical life of pipe is defined as the total quantity of slurry flowing through the pipe which will reduce the wall thickness of the pipe by internal wear to about 1/16 inch, divided by the quantity of slurry pumped per year (280 days). The theoretical life of the pipe will have to be developed either from experience or experimentation with the particular type of material.

Since most hydraulic transport systems will not be operating continuously for 280 days per year, the effective life of pipe will be greater than the theoretical and will be equal to the theoretical life divided by the percent operating time, as a fraction of 100. The annual costs for the pipeline in the table are computed on the basis of capital recovery at 7-percent interest over the 20-year life of the system of the sum of the initial investment for procurement and installation of the line and the present values of the periodic replacement costs or the provision of added pipe thickness initially in lieu of replacement. The salvage value of pipe is considered to be equal to the cost of removal.

Energy cost per 1000 feet versus booster spacing. Figure 4-10 presents the energy costs per year per 1000 feet of pipeline for operating the system with horsepower, booster station spacing, and percent operating time being the variables. The unit rate for electrical energy has been assumed as \$0.021 per kilowatt hour, this figure being the countrywide average as of July 1976. Since energy rates vary significantly from one geographical area to another, an energy rate factor adjustment will be necessary where the actual rate differs from the assumed \$0.021 rate. This chart is based on the formula:

Energy cost per 1000 feet = [0.021 x hp (per pump) x 2 (pumps) x 0.746 (kw/hp) x 280 (days) x 24 (hrs/day) x % operating time] ÷ [booster spacing (1000 ft) x 100]

$$= \frac{2.1055 \times \%\ \text{operating time} \times \text{hp (per pump)}}{\text{Booster spacing (1000 ft)}}$$

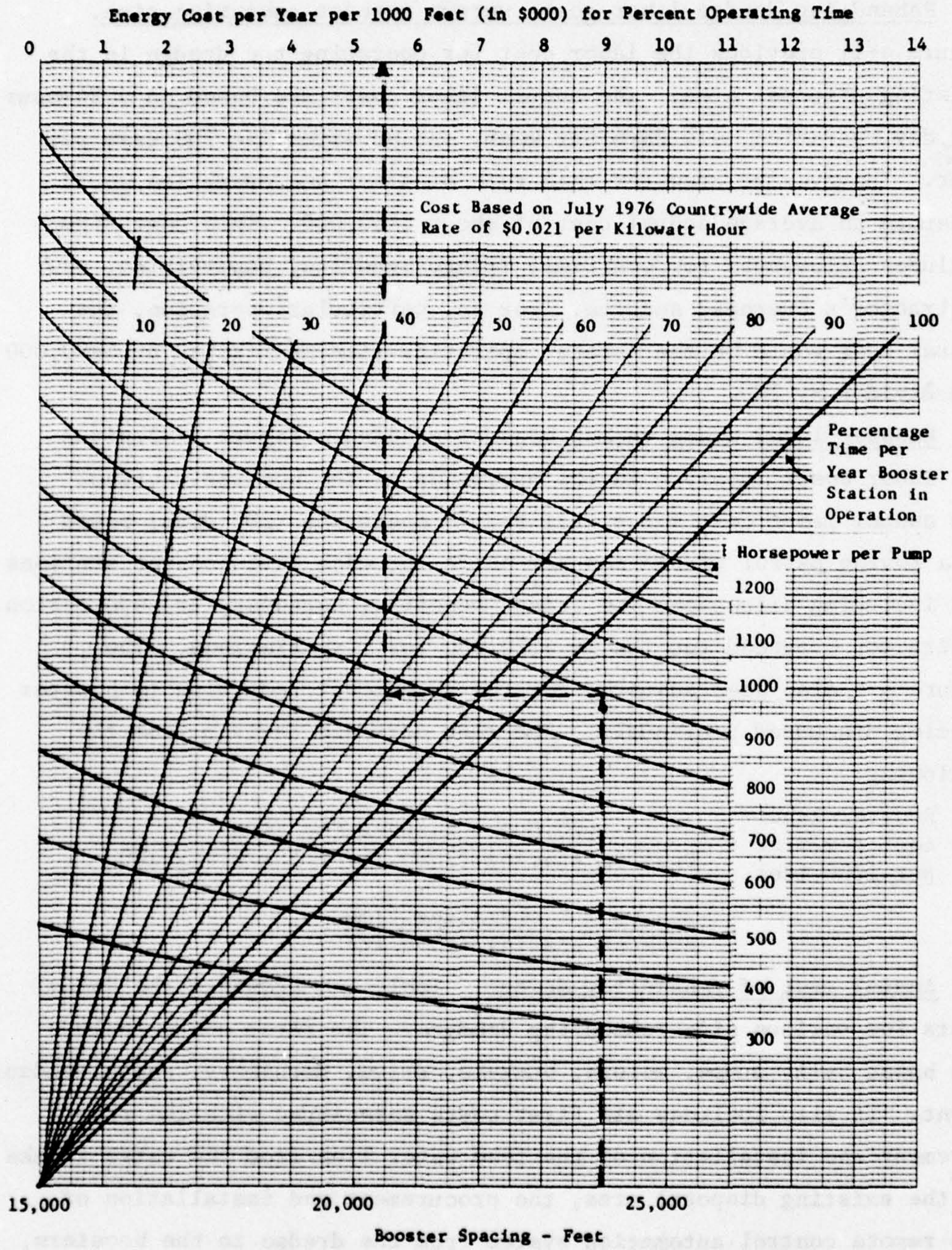

Figure 4-10. Energy Cost per 1000 Feet vs Booster Spacing for Variable Horsepower and Percent Operation

Rehandling dredge labor costs versus percent operating time. Figure 4-11 provides the labor cost for operating the dredge in the existing disposal area. The annual labor costs are based on a 24-hour per day operation, six days per week, and an effective 280 days per year. The average crew for this type of plant and operation would generate an average annual cost of about $900,000. This cost figure includes allowances for overtime, fringe benefits, supervision, and contractor's overhead and fee. For any particular operation, the annual cost would be the percent operating time multiplied by $900,000 and divided by 100.

Booster labor costs versus booster spacing. Figure 4-12 gives the labor costs involved in the operation of the booster station. The annual labor cost for a full year's operation (280 days) based on a roving patrol of one man per shift for each five booster stations and including allowances for fringe benefits, necessary transportation, contractor overhead and fee is $120,000 for five stations. The figure has also been adjusted for the 10 percent reduction in booster spacing discussed previously. The cost data are derived from the following:

$$\begin{array}{l}\text{Booster labor} \\ \text{cost per year} \\ \text{per 1000 feet}\end{array} = \frac{120{,}000 \times \%\ \text{operating time}}{\text{Booster spacing (1000 ft)} \times 5 \times 0.9 \times 100}$$

$$= \frac{266.67 \times \%\ \text{operating time}}{\text{Booster spacing (1000 ft)}}$$

Annual cost of rehandling dredge. Table 4-4 presents the annual costs for various size rehandling dredges. The first costs include the basic hull, pumps, motors, buckets, drive, machinery, and attendant plant. It also includes all first costs associated with the procurement and installation of the feed water line from the water intake to the existing disposal area, the procurement and installation of the remote control automation system from the dredge to the boosters, the excavation of a basin in the disposal area for flotation of the dredge and the assembling of the dredge in the basin. The annual

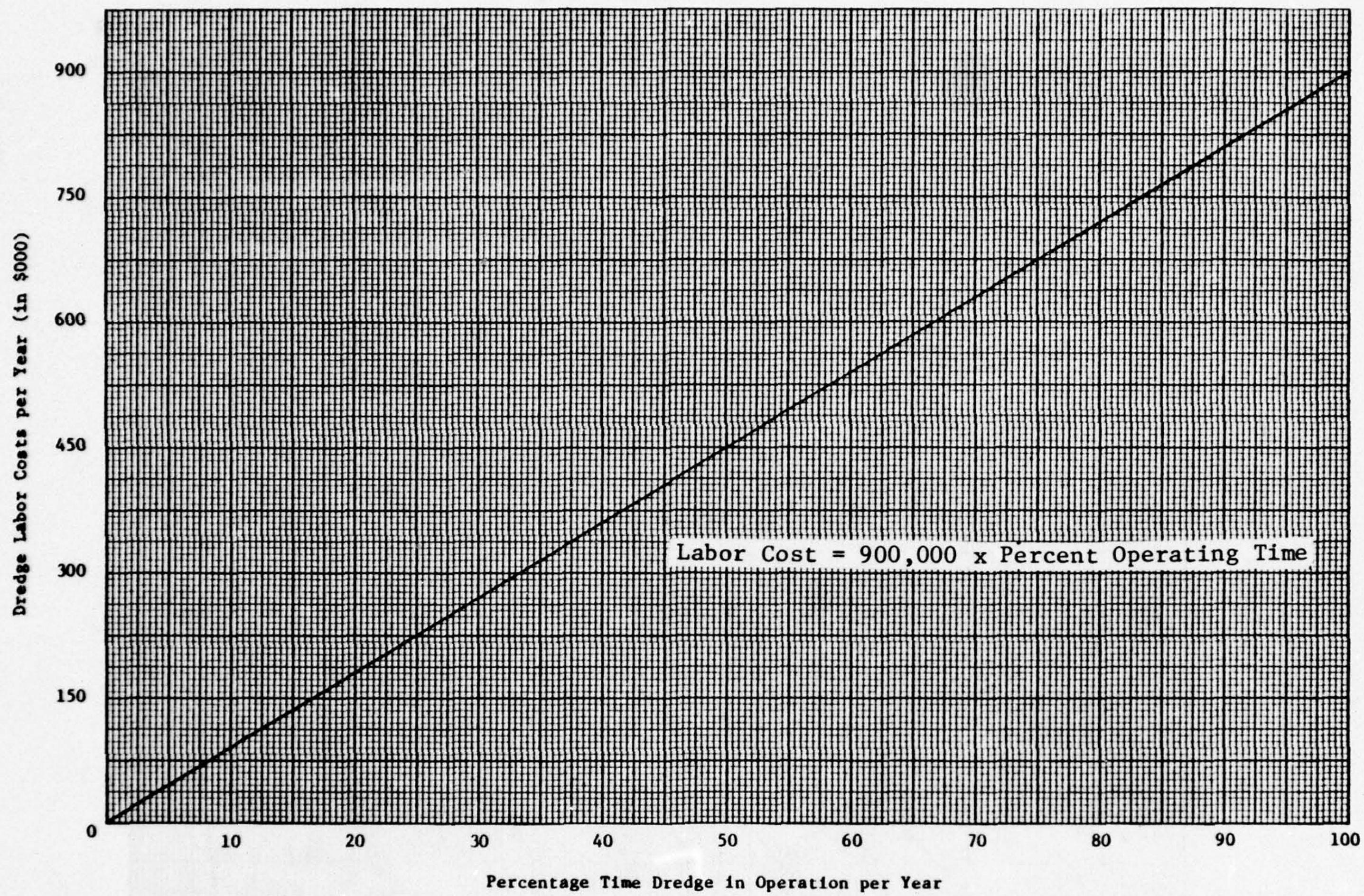

Figure 4-11. Dredge Labor Costs vs Percent Operating Time

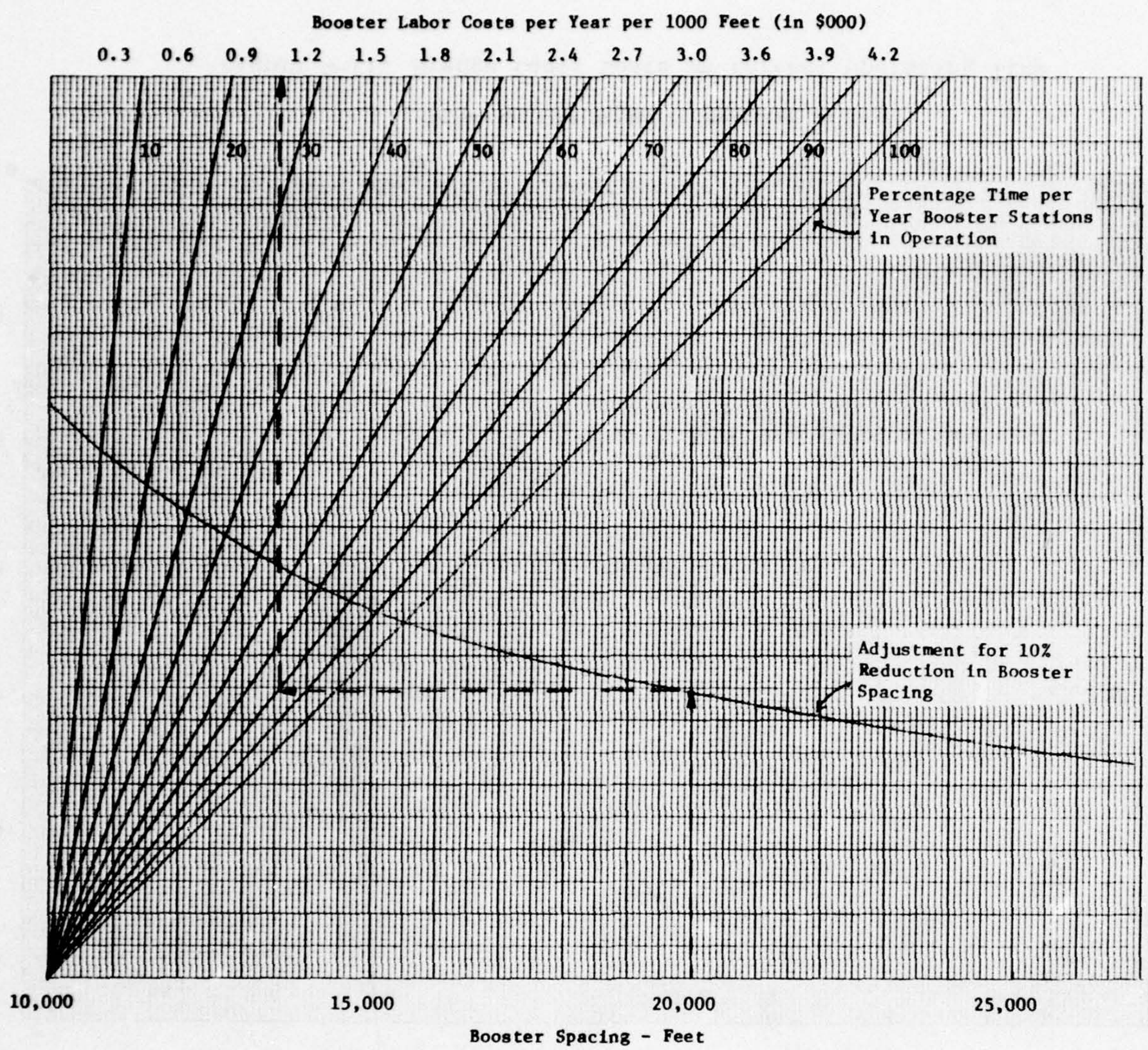

Figure 4-12. Booster Labor Costs vs Booster Spacing

charge for first costs is based on capital recovered at 7-percent for a 20-year life. The annual costs also include allowances for insurance, maintenance, repair, lay up, and other miscellaneous costs as applicable.

Table 4-4

Annual Costs of Rehandling Dredges

Dredge Size	Annual Cost (Total)
8"	$350,000
10"	400,000
12"	450,000
14"	500,000
16"	550,000
18"	600,000
20"	650,000

The annual costs shown are considered to be fixed charges irrespective of percent operating time, it being assumed that a 20-year operation (equal to the life of the dredge) is the maximum reasonable expectation for the long-distance pipeline slurry transport concept. The salvage value of the dredge is assumed to be negligible.

Illustrative Example of Design Determination and Costing

To illustrate how the previously developed figures and tables can be used to design long-distance transport systems for a specific set of conditions, to estimate their base costs, and to select the most economical alternative, the following step-by-step procedure is presented.

Steps 1 through 3,* list given conditions.

Density of water - 1000 grams/liter

Density of disposal area material - 1600 grams/liter

Density of slurry - 1300 grams/liter

Annual quantity of material to be removed from disposal area - 2,000,000 cubic yards/year of in situ material

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* Step numbers correspond to step numbers on pages 49-59.

Critical velocity, V_c, of material - 9 feet/second for 12" diameter pipe

Total dynamic head - 500 feet

Theoretical life of pipe - 5 years

Step 4, solids ratio. From Figure 4-2, the ratio of disposal area solids to slurry solids = 2 to 1

$$\text{Formula, } R = \frac{d_a - d_w}{d_s - d_w} = \frac{1600 - 1000}{1300 - 1000} = 2 \text{ to } 1$$

Step 5, slurry discharge rate. From Figure 4-3, the quantity of slurry, Q_s, required for an annual production of 2,000,000 cubic yards = 4.46 cubic feet/second

$$\text{Formula, } Q_s = \frac{P \times R}{896{,}000} = 4.46 \text{ cubic feet/second}$$

Step 6, critical velocity. From Figure 4-4, determination of critical velocities for different diameter pipes (i.e., D_2 in Fig. 4-4) based on given condition that V_c for 12" diameter pipe (i.e., D_1 in Fig. 4-4) = 9 feet/second.

Pipe Diameter	Factor from Formula $V_c \propto \sqrt{D}$ *	Critical Velocity V_c, feet/second
10"	$\sqrt{10/12}$	0.91 x 9.0 = 8.2
12"	$\sqrt{12/12}$	1.00 x 9.0 = 9.0
14"	$\sqrt{14/12}$	1.08 x 9.0 = 9.7
16"	$\sqrt{16/12}$	1.16 x 9.0 = 10.4
18"	$\sqrt{18/12}$	1.23 x 9.0 = 11.0

Step 7, quantity of slurry at critical velocity. From Figure 4-5, determination of quantity of slurry for the critical velocities and percent operating time. (Also from formula)

$$Q_s = V_c \times \frac{\pi D^2}{4}$$

* Calculation required in varying from a 12" diameter pipe.

Pipe Diameter	V_c	Q_s at V_c	% Operating Time*
10"	8.2	4.48	4.46/4.48 = 99%
12"	9.0	7.07	4.46/7.07 = 63%
14"	9.7	10.36	4.46/10.35 = 43%
16"	10.4	14.52	4.46/14.52 = 31%
18"	11.0	19.44	4.46/19.44 = 23%

Step 8, booster spacing. From Figure 4-6, determination of booster station spacing for the different pipe diameters and Q_s at the respective critical velocities. Also obtained from formula:

$$\text{Booster Spacing} = \frac{H_t \times D \times 2g}{0.028 \times V_c^{1.75}}$$

Pipe Diameter	Theoretical Booster Spacing, Feet	Design Spacing, Feet
10"	24,200	21,800
12"	24,600	22,200
14"	25,200	22,700
16"	25,500	23,000
18"	26,000	23,400

Step 9, brake horsepower. From Figure 4-7, determination of the brake horsepower required per pump for the quantities of slurry, Q_s, for the respective pipe sizes. Also obtained from formula:

$$BHP = 0.04727\ Q_x \times d_s$$

Pipe Diameter	Q_s at V_c	BHP per Pump
10"	4.48	275
12"	7.07	435
14"	10.36	635
16"	14.52	890
18"	19.44	1195

* % Operating Time = Q_s (step 5)/Q_s at V_c (step 7).

Step 10, water requirements. From Figure 4-8, determination of the water requirements to fluidize the material to the slurry density and to provide the necessary water for flotation of the dredge as the excavated part of the basin increases in size. Also obtained from the formulas:

$$\text{For slurry} = \left(\frac{2600 - d_s}{1600}\right) Q_s$$

$$\text{For flotation} = \frac{Q_s}{R}$$

Pipe Diameter	Water Requirements, Cubic Feet/Second Slurry	Flotation	Total
10"	3.6	2.2	5.8
12"	5.7	3.5	9.2
14"	8.4	5.2	13.6
16"	11.8	7.3	19.1
18"	15.8	9.7	25.5

The pumping system for the water requirements will be identical to the system at a booster station (to provide for a means to clear the pipeline in the event of a breakdown of dredge pumps). It will be found that the increased frictional losses in the line resulting from the slightly higher velocities required to provide for the water requirements as compared to the slurry will be more than compensated by the shorter pipeline distance (5000 feet). The net result will be a reduced dynamic head which can be developed adequately by only one pump.

At this point the basic design elements of the pipeline system have been established for different pipeline sizes. From these data, the costs for construction and operation of the several possible system configurations can be developed.

Step 11, booster system cost. From Figure 4-9, the booster system cost per year per 1000 feet is extracted as follows:

Pipe Diameter	Booster Spacing, Feet	BHP per Pump	Cost per Year per 1000 Feet
10"	24,200	275	$2080
12"	24,600	435	2690
14"	25,200	635	3400
16"	25,500	890	4340
18"	26,000	1195	5410

Step 12, pipe costs. From Table 4-3, the cost of the pipe and its installation, per year per 1000 feet are extracted as follows:

Pipe Diameter	% Operating Time	Effective Life of Pipe, Years	Cost per Year per 1000 Feet
10"	99	5	$4100
12"	63	8	3700
14"	43	12	3400
16"	31	16	3800
18"	23	20	3300

Step 13, energy cost. From Figure 4-10, the energy cost of the system is extracted from the figure or derived from the previously developed formula as follows:

Pipe Diameter	Booster Spacing, Feet	% Operating Time	BHP per Pump	Energy Cost per 1000 Feet
10"	24,200	99	275	$2370
12"	24,600	63	435	2350
14"	25,200	43	635	2280
16"	25,500	31	890	2250
18"	26,000	23	1195	2230

Step 14, labor costs. From Figure 4-11, the labor costs for operating the dredge are extracted as follows:

Pipe Diameter	% Operating Time	Dredge Labor Costs per Year
10"	99	$891,000
12"	63	567,000
14"	43	387,000
16"	31	279,000
18"	23	207,000

The labor costs for operating the booster stations are extracted from Figure 4-12 as follows:

Pipe Diameter	% Operating Time	Booster Spacing, Feet	Booster Labor Costs per Year per 1000 Feet
10"	99	24,200	$1090
12"	63	24,600	680
14"	43	25,200	460
16"	31	25,500	320
18"	23	26,000	240

Step 15, dredge plant costs. The annual costs for the rehandling dredge and the activities related thereto are extracted from Table 4-4 as follows:

Dredge Size	Yearly Cost, Total
10"	$400,000
12"	450,000
14"	500,000
16"	550,000
18"	600,000

Cost summary. The individual cost items can now be consolidated and costs developed for variable distances. For simplicity, the distances used are in multiples of 100,000 feet. A summary sheet, Table 4-5, depicts both the design data developed for the given conditions of the illustrative example and the resultant base cost data associated with the different system configurations. The cost summary is also presented in graph form on Figure 4-13, which gives the unit costs for variable distances.

Analysis of the summary data on Table 4-5 indicates that for the given conditions of the illustrative example, the 14-inch diameter pipeline system is the most economical, irrespective of the length of the system. For a different set of conditions, it is possible that the diameter of the most economical system might be different for different transport distances.

Table 4-5

Illustrative Example - Design and Cost Data Summary

Item	Pipeline Diameter - Inches				
	10	12	14	16	18
	Design Data				
Ratio of disposal area solids to slurry solids	2:1	2:1	2:1	2:1	2:1
Quantity of slurry required for annual production of 2,000,000 cu yds-cu ft/sec	4.46	4.46	4.46	4.46	4.46
Critical velocities-ft/sec	8.2	9.0	9.7	10.4	11.0
Quantity of slurry at critical velocity cu ft/sec	4.48	7.07	10.36	14.52	19.44
Percent operating time	99	63	43	31	23
Booster station spacing in ft	24,200	24,600	25,200	25,500	26,000
BHP per pump	275	435	635	890	1,195
Water requirements for slurry and flotation of dredge - cu ft/sec	5.8	9.2	13.6	19.1	25.5
Effective life of pipe - yrs	5	8	12	16	20
	Cost Data - Dollars				
Booster labor/1000 ft/yr	1,090	680	460	320	240
Booster plant/1000 ft/yr	2,080	2,690	3,400	4,340	5,410
Pipeline/1000 ft/yr	4,100	3,700	3,400	3,800	3,300
Energy/1000 ft/yr	2,370	2,350	2,280	2,250	2,230
Subtotal	9,640	9,420	9,540	10,710	11,180
Dredge plant/yr	400,000	450,000	500,000	550,000	600,000
Dredge labor/yr	891,000	567,000	387,000	279,000	207,000
Subtotal	1,291,000	1,017,000	887,000	829,000	807,000
Distance	**Total Costs for 2,000,000 Cu Yds**[a]				
100,000 ft	2,255,000 (1.13)	1,959,000 (0.98)	1,841,000 (0.92)	1,900,000 (0.95)	1,925,000 (0.96)
200,000 ft	3,219,000 (1.61)	2,901,000 (1.45)	2,795,000 (1.40)	2,971,000 (1.49)	3,043,000 (1.52)
300,000 ft	4,183,000 (2.09)	3,843,000 (1.92)	3,749,000 (1.87)	4,042,000 (2.02)	4,161,000 (2.08)
400,000 ft	5,147,000 (2.57)	4,785,000 (2.39)	4,703,000 (2.35)	5,113,000 (2.56)	5,279,000 (2.64)
500,000 ft	6,111,000 (3.06)	5,727,000 (2.86)	5,657,000 (2.83)	6,184,000 (3.09)	6,397,000 (3.20)

[a]Numbers in parentheses are costs per cu yd.

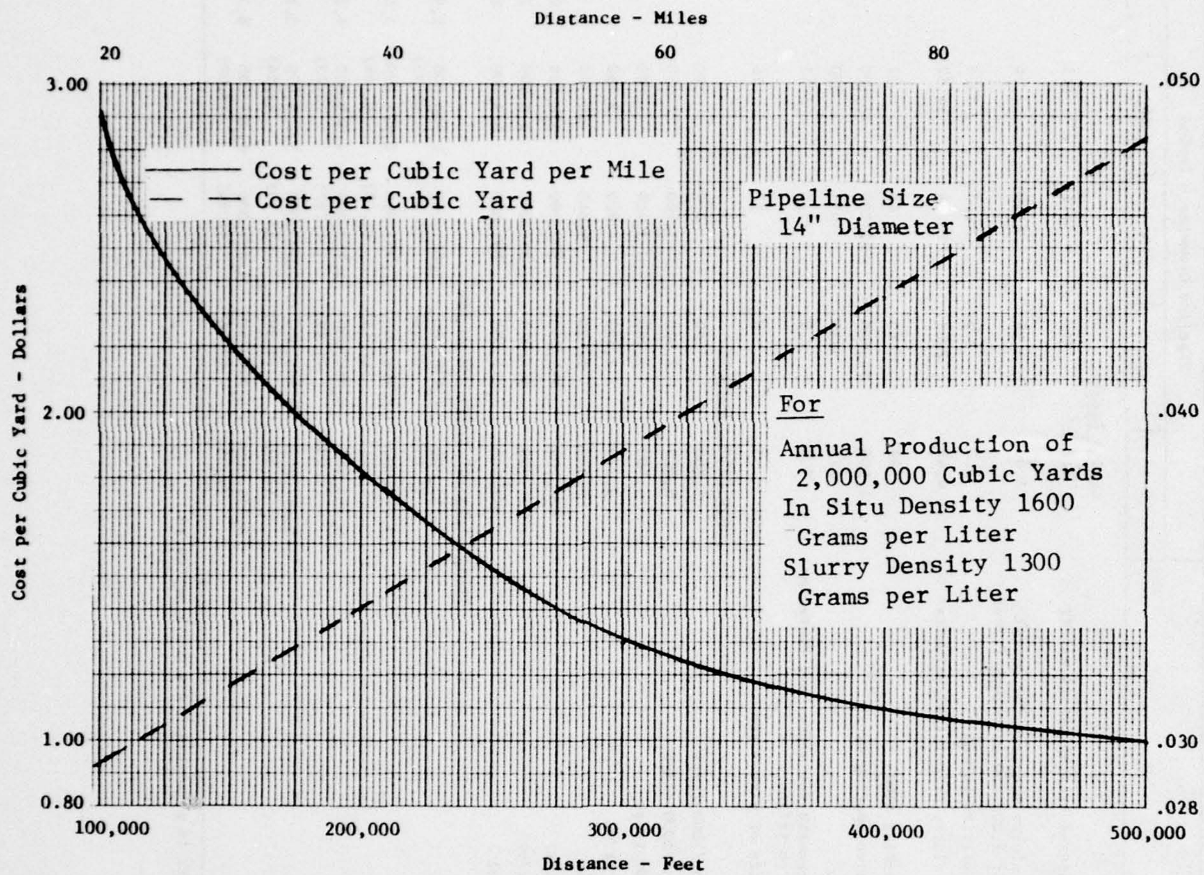

Figure 4-13. Illustrative Example - Cost Data for Most Economical Size System

It should be noted that all of the design figures, tables, and formulas were developed for an effective 280 days of operation per year. This is generally an average situation in the geographic areas where climatic conditions are conducive to operations during all seasons of the year. However, there are certain sections of the country, particularly the Great Lakes, upper New England, and upper Mississippi River regions where weather conditions are such that operations cannot be conducted during most of the late fall, winter, and early spring months. In these areas, the effective number of days of continuous operation is most probably less than 280 days. However, the figures and tables are still valid for those applications provided they are developed in accordance with the following procedures:

- Develop all design and cost data for the 280 days of operation.
- Compute in percents the actual days of operation per year divided by 280 days.
- Any system which shows a percent operating time less than that computed in the step above will be satisfactory for the condition of reduced operation per year and the derived data will apply.

Summary Costs for Centrifugal Pumping System

The illustrative example is for only one set of conditions and as such it only serves the purpose of demonstrating the step by step procedure to be followed in developing design and cost data for a particular set of conditions. For planning purposes and for approximate comparative analysis of base costs for different sets of conditions, wherein in situ densities, slurry densities, annual quantities to be handled, and pipeline distances vary, groups or families of curves would be required. To this end, summary design and cost data sheets similar to Table 4-5 were developed for the conditions given in the illustrative example, except that in situ densities varied between 1300 and 1600 grams per liter, slurry densities varied from 1200 to

1500 grams per liter as applicable, annual quantities varied from 500,000 cubic yards to 4,000,000 cubic yards, and distances varied by 100,000 feet increments up to 500,000 feet.

A theoretical life of pipe of five years has been assumed for all cases even though it is recognized that because of the different in situ densities to be considered (1300 to 1600 grams per liter), and range of slurry densities as well as slightly different velocities for different size pipes, the wear effect on pipe for the different conditions probably would not be exactly the same. However, because of the lesser abrasiveness of the type material to be handled, it is believed the deviations in the theoretical life of pipe would be minor and, considering the purpose of the overall cost data, its effect thereon would be negligible.

From these voluminous data, a series of four figures and tables were prepared for varying in situ densities. Figures 4-14 through 4-17 present the "base" costs for a hydraulic pipeline transport system for any desired set of conditions. The curves shown in these figures are based on an annual quantity of 4,000,000 cubic yards. However, the accompanying table on each figure provides multiplying factors for adjusting the 4,000,000 cubic yard curve for varying volume levels and slurry densities. It is to be noted that the cost curves shown are on the basis of cost per cubic yard as well as cost per cubic yard per mile.

It should be noted that the cost of acquiring the necessary rights of way for the pipeline and booster stations, or the acquisition and related costs of the distant disposal area, are not included in the cost data. With respect to the latter, the distant disposal area is only the receptacle for the dredged material. The activities required in the disposal area to effect the productive use of the dredged material is an independent operation and as such is not considered as being an element of the transport system. The transport system only serves as the means by which the dredged material is carried from one location to another.

Annual Quantity cu yds	Pipeline Distance (000 ft)	Multiplier Slurry Density 1200
4,000,000	100 200 300 400 500	1.00
3,000,000	100	1.17
	200	1.13
	300	1.11
	400	1.11
	500	1.11
2,000,000	100	1.48
	200	1.40
	300	1.37
	400	1.36
	500	1.36
1,000,000	100	2.22
	200	2.08
	300	2.02
	400	1.99
	500	1.99
500,000	100	3.63
	200	3.32
	300	3.18
	400	3.11
	500	3.09

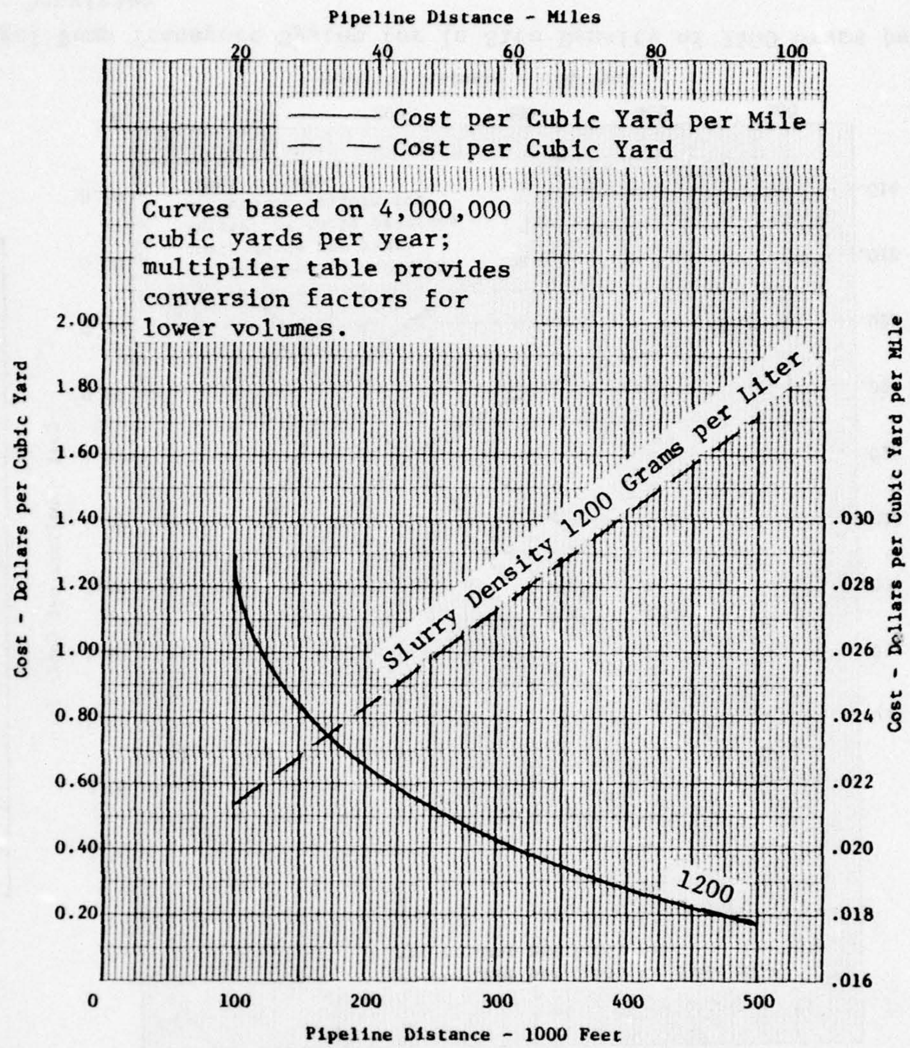

Figure 4-14. Cost of a Centrifugal Pump Transport System for In Situ Density of 1300 Grams per Liter for Variable Slurry Densities

Annual Quantity cu yds	Pipeline Distance (000 ft)	Multiplier Slurry Density 1200	1300
4,000,000	100	1.00	
	200		
	300		
	400		
	500		
3,000,000	100	1.18	1.13
	200	1.14	1.13
	300	1.11	1.12
	400	1.10	1.11
	500	1.09	1.11
2,000,000	100	1.52	1.56
	200	1.42	1.40
	300	1.39	1.37
	400	1.37	1.34
	500	1.35	1.34
1,000,000	100	2.50	2.20
	200	2.23	2.08
	300	2.12	2.03
	400	2.06	2.00
	500	2.01	1.99
500,000	100	3.61	3.58
	200	3.23	3.32
	300	3.06	3.18
	400	2.98	3.11
	500	2.91	3.07

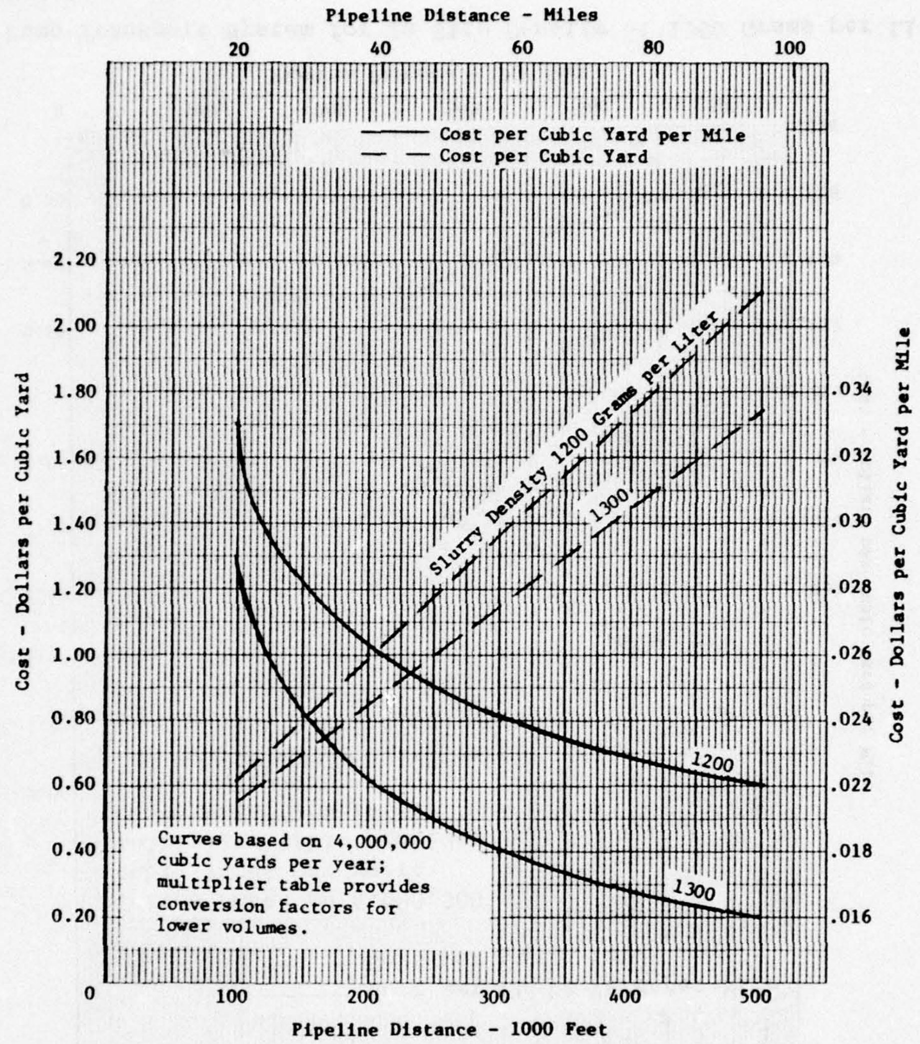

Figure 4-15. Cost of a Centrifugal Pump Transport System for In Situ Density of 1400 Grams per Liter for Variable Slurry Densities

Annual Quantity cu yds	Pipeline Distance (000 ft)	Multiplier Slurry Density 1200	1300	1400
4,000,000	100			
	200			
	300		1.00	
	400			
	500			
3,000,000	100	1.15	1.17	1.17
	200	1.15	1.15	1.14
	300	1.13	1.14	1.13
	400	1.12	1.12	1.12
	500	1.12	1.11	1.11
2,000,000	100	1.42	1.48	1.49
	200	1.39	1.41	1.40
	300	1.37	1.38	1.37
	400	1.35	1.35	1.35
	500	1.35	1.34	1.34
1,000,000	100	2.15	2.25	2.28
	200	2.01	2.08	2.06
	300	1.93	2.00	1.97
	400	1.88	1.93	1.92
	500	1.86	1.89	1.89
500,000	100	3.28	3.48	3.68
	200	3.01	3.09	3.35
	300	2.87	2.94	3.22
	400	2.80	2.83	3.15
	500	2.74	2.76	3.10

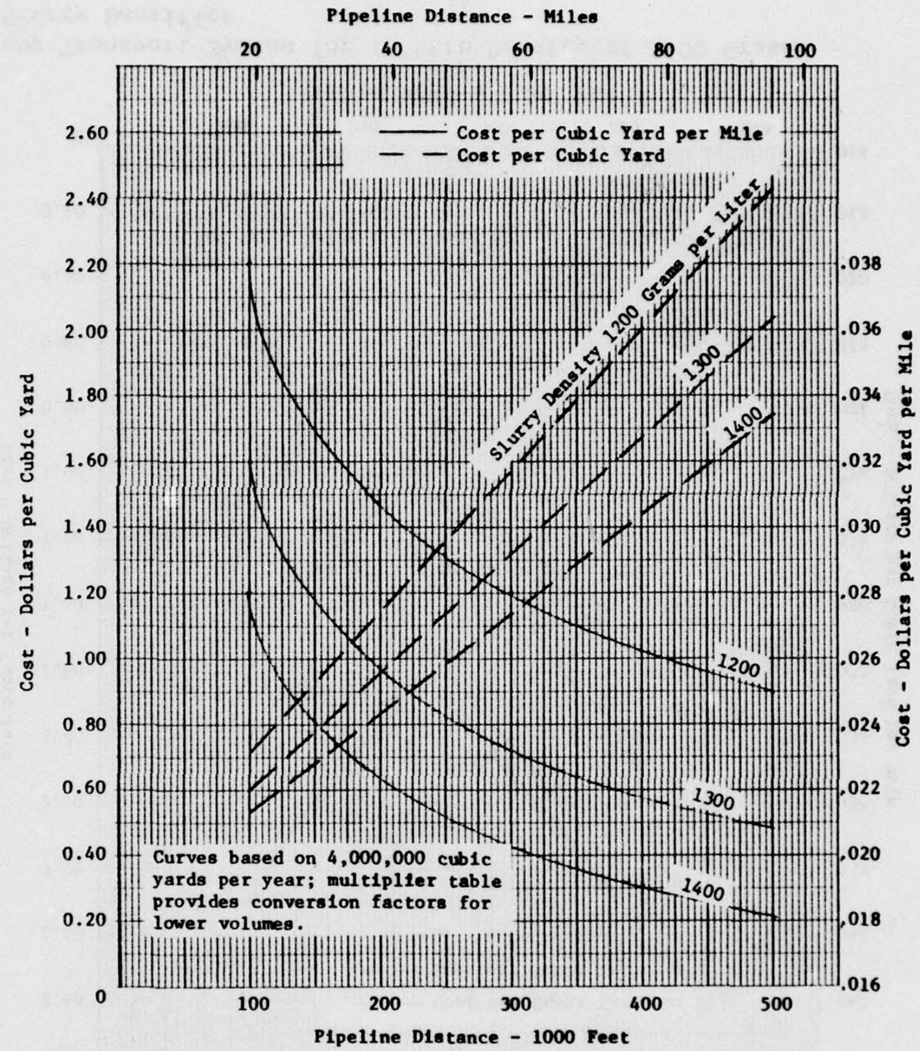

Figure 4-16. Cost of a Centrifugal Pump Transport System for In Situ Density of 1500 Grams per Liter for Variable Slurry Densities

Annual Quantity cu yds	Pipeline Distance (000 ft)	Multiplier Slurry Density 1200	1300	1400	1500
4,000,000	100	1.00			
	200				
	300				
	400				
	500				
3,000,000	100	1.13	1.17	1.16	1.15
	200	1.13	1.14	1.13	1.13
	300	1.12	1.13	1.13	1.13
	400	1.12	1.12	1.12	1.13
	500	1.11	1.12	1.12	1.13
2,000,000	100	1.36	1.44	1.46	1.48
	200	1.32	1.38	1.38	1.41
	300	1.31	1.35	1.37	1.38
	400	1.30	1.33	1.35	1.38
	500	1.30	1.32	1.34	1.37
1,000,000	100	2.02	2.25	2.18	2.26
	200	1.88	2.11	2.04	2.13
	300	1.81	2.03	2.02	2.06
	400	1.77	1.98	1.98	2.04
	500	1.75	1.96	1.95	2.01
500,000	100	3.05	3.56	3.51	3.65
	200	2.77	3.24	3.24	3.36
	300	2.65	3.07	3.15	3.25
	400	2.60	2.98	3.07	3.21
	500	2.57	2.93	3.02	3.17

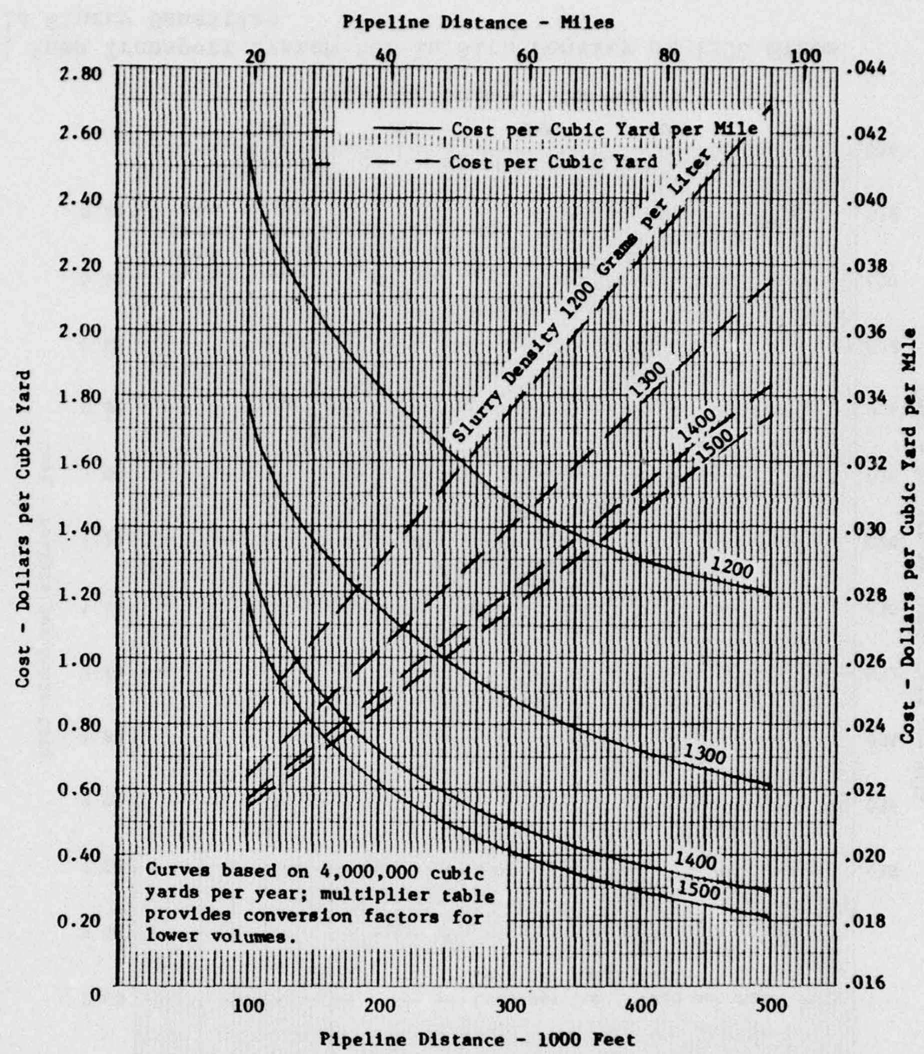

Figure 4-17. Cost of a Centrifugal Pump Transport System for In Situ Density of 1600 Grams per Liter for Variable Slurry Densities

The cost of the right-of-way is a cost which must be included in the total cost of the system. However, because of the wide variations in real estate costs in different areas, no attempt has been made to include a definitive allowance for such costs in the various figures and tables. The planner should include the necessary allowance for these costs on the basis of known or realistic real estate values along the particular route. Generally, the pipeline route in rural areas will most likely be sited along a powerline or highway right-of-way. The real estate rights would be by easement rather than fee title, and the width of the easement would be minimal. Under these conditions, it is believed that rights-of-way costs will be a minor part of the overall transport costs and in most cases will not exceed 3 to 5 percent of the total cost.

Centrifugal Pumping System - Cost Sensitivity Analysis

The data depicted by the "base"* cost curves in Figures 4-14 through 4-17 reflect conditions where the values applicable to the principal design parameters are at their lowest range, and therefore most favorable from a cost standpoint to the long distance transport of dredged material. However, where less favorable conditions exist which, in turn, result in changes in the values of system design parameters, such as an increase in the required critical velocity or an increase in the coefficient of friction, resulting transport costs could increase by as much as 100%. To evaluate the impacts of such design changes on these costs, a sensitivity analysis was conducted with a pipeline model. Since such analyses are inherently time consuming, the model was computerized to expedite this effort.

Basically, the computer model was designed to mirror the systems design and costing process described in the preceding pages. The values for the three principal design parameters, (1) the critical velocity, (2) the coefficient of friction, and (3) the total discharge head are fixed for the "base" condition. All unit costs are also

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* For a definition of "base" conditions, refer to page 47.

fixed in 1976 dollars for the "base" condition. Any or all of these fixed values could be examined in terms of changes to these values and their impacts on total system costs. In order to keep the scope of the sensitivity analysis in manageable proportions, only the more important design and/or cost elements were evaluated.

The design elements considered in this analysis were (1) critical velocity and (2) coefficient of friction. Total discharge head was not considered because the value of this design parameter was chosen at about its practical maximum and should remain at this level for a long distance transport application.

In the unit cost area the impact of varying energy and pipe laying costs on total system costs was examined because of the potential for substantial variations in these elements for differing transport system applications. Also, the effect on total system costs of providing a backup pump at each booster station to increase operational reliability was examined.

In developing the computer model for the sensitivity analysis, the capability to apply an adjustment factor to each of the design parameters and unit cost elements was built into the model. The value of the adjustment factor is based upon deviations from the "base" condition data. For example, if a 25% increase in the coefficient of friction is being examined, the adjustment factor for this parameter will be 1.25. This means that the "base" condition coefficient of friction of 0.028 is multiplied by 1.25 resulting in the use of a 0.035 coefficient in the Darcy-Weisbach formula to determine booster station spacing. In a similar manner adjustment factors are applied to each variable under consideration.

A special feature was incorporated in the model to permit the separation of total pipe costs into two elements, pipe steel cost and pipe laying cost. Since pipe laying costs are affected by subsurface conditions and terrain along the alignment of the pipeline route, while pipe steel costs will generally remain independent of

route considerations, this special cost breakout permits the examination of terrain difficulty and related pipe laying costs on total system costs.

For a better understanding of the parameters being examined a brief discussion of the technical basis for this potential variation follows:

Critical Velocity. The "base" condition for critical velocity is 9.0 feet per second for the 12" diameter pipe and increasing to 11.0 feet per second for the 18" diameter pipe. These values are realistic for flow without settlement for extremely small particle size material of the type generally associated with the soft muds and fine silts. It is assumed that the material for the "base" condition will be free of any significant amounts of sand, either of the fine or medium grain size. In the sensitivity analysis the critical velocity is increased 25 percent and 50 percent to measure the effect of critical velocity changes on total system costs. It is not believed, however, that values above 25 percent increase will be necessary to pump the type material considered in this study. Thus, a requirement for an increase of the critical velocities in excess of about 11.5 feet per second for the 12" diameter pipe and 14.0 feet per second for the 18" diameter pipe is considered unlikely from the standpoint of settlement of the material in the pipe. Although in navigation dredging operations it often proves more economical to pump material at velocities much higher than the critical velocity, for long distance slurry applications the economies related to slurry velocity favor lower velocities. In navigation dredging operations the use of higher pumping velocities results in the job being completed sooner with savings in plant and labor costs which more than compensate for any increase in fuel costs. However, where a series of booster stations are involved the higher velocities result in (1) a decrease in booster station

spacing, (2) an increase in the number of booster stations, and (3) an increase in the power requirements, all of which serve to increase costs. The only compensating factor is that higher velocities tend to decrease labor and plant rental costs. The net effect of increasing slurry velocity for a long distance transport system is a significant increase in total system costs. The sensitivity analysis substantiates this fact by showing how total system costs increase with increases in velocity. (Refer to Table 4-6.)

Coefficient of Friction. The "base" value of 0.028 selected for the coefficient of friction in the Darcy-Weisbach formula is generally accepted as a reasonable value for average type conditions. However, it is possible under adverse conditions a higher value for this coefficient may be appropriate. To demonstrate the effect on total system costs of increases in the value to a coefficient of friction a sensitivity analysis was conducted for this parameter with increases to 50 percent over the base value. In actual practice increases beyond 25 percent are considered unlikely based on the type material under consideration.

Unit Cost of Energy. The cost of energy was derived to be $0.021 per kilowatt hour. This value was the countrywide average rate for electric power as of July 1976. Since the cost of electric power varies significantly from one geographical location to another, in some regions the actual rate may be as much as 50 percent greater than the countrywide average rate. To evaluate the impact of cost increases in electric power on total system costs increases in energy cost of up to 50 percent were examined.

Unit Cost of Laying Pipe. The "base" condition cost data for laying pipe assumes the following favorable conditions:

1. Gentle rolling terrain
2. No steep slopes

3. Only minor stream, highway, or railroad crossings

4. The pipeline alignment traverses areas of light to medium congestion or development

5. No difficult excavation or clearing requirements along the right of way

The effects of adverse conditions for the above factors on pipe laying costs are estimated to be within the following ranges:

1. Moderately hilly terrain with occasional steep slopes (5-10 percent increase)*

2. Stream, railroad, or highway crossings of a greater magnitude (5-15 percent increase)

3. Traverse areas of heavy congestion (50 percent increase)

4. More difficult excavation or clearing (25-50 percent increase)

If more than one adverse condition exists, the net effect on pipe laying cost is compounded. To evaluate the sensitivity of pipe laying cost on total system costs increases in pipe laying cost up to 50% were examined.

Cost of Standby Pump. The "base" condition pipeline system does not include provisions for a third standby pump at each booster station for emergency purposes or to permit routine preventive pump maintenance. It would be prudent from a reliability standpoint to provide a standby pump at each booster station which can be substituted for either of the other two pumps whenever the need arises. As a result the cost impact of providing an additional pump at each booster station is evaluated.

Cost Sensitivity Analysis Results. Since the "base" condition cost results presented in Figures 4-14 through 4-17 are desired for varying in situ and slurry densities, the initial cost sensitivity runs were made for different combinations of in situ and slurry

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*All percentages should be weighted by distances affected.

densities. The results of this portion of the analysis indicated that the deviations between increases over base costs for different in situ and slurry density combinations were minimal in all instances. In fact, when the results of the increases over base costs for the 1600/1400 and 1500/1200 in situ and slurry density combinations were averaged, the cost results of varying any other in situ and slurry density combinations fell within two percent of the above averaged data. Therefore, to simplify the presentation of the cost sensitivity results, the cost sensitivity results are based upon an average of the 1600/1400 and 1500/1200 in situ/slurry density combinations which can be considered applicable to all other combinations.

Next, several computer model runs were made to determine the effect increases in the values of the principal parameters and certain cost items would have on base costs for annual disposal area excavation quantities of 500,000, 1,000,000, 2,000,000, 3,000,000, and 4,000,000 cubic yards and for distances of 100,000, 200,000, 300,000, and 500,000 feet. The "base" value of each parameter or cost item was increased by 25 and 50 percent and an extra standby pump was included at each booster station. Table 4-6 summarizes the results of these runs. The data in the table are the cost multiplier factors which when applied to the comparable "base" costs (Figures 4-14 through 4-17) will yield the cost of the transport system. The net effect of value changes in more than one parameter is the product of the respective cost multiplier factors. For example, at an annual production level of 2,000,000 cubic yards and a transport distance of 300,000 feet, the net cost multiplier factor is derived as follows:

Parameter	% Increase in Parameter Value	Cost Multiplier Factor (from Table 4-6)
Critical velocity	25	1.29
Energy cost	50	1.10
Pipe laying cost	50	1.07
Standby pump	Yes	1.07

Net effect = 1.29 x 1.10 x 1.07 x 1.07 = 1.62

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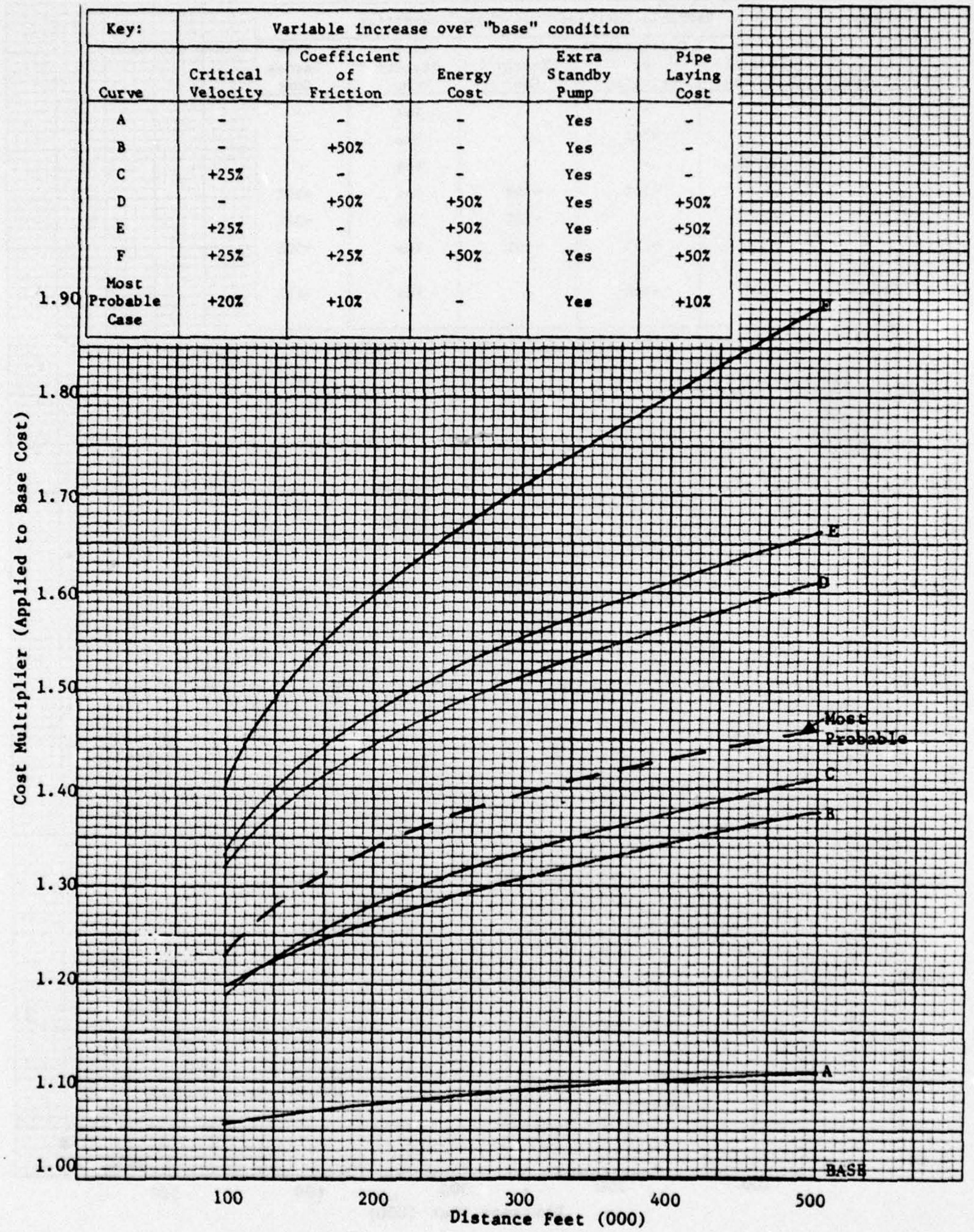
Table 4-6

Summary Results of Cost Sensitivity Analysis
(Cost Multiplier Factors)

		Percent Increase over "Base" Values								Addition of Extra Pump at Each Booster Station
Annual Quantity cu. yds.	Distance Feet (000)	Critical Velocity 25%	50%	Coefficient of Friction 25%	50%	Energy Costs 25%	50%	Pipe Laying Costs 25%	50%	
	100	1.23	1.51	1.10	1.21	1.06	1.10	1.02	1.04	1.06
	200	1.29	1.63	1.12	1.24	1.06	1.12	1.02	1.04	1.06
4,000,000	300	1.32	1.70	1.13	1.26	1.07	1.14	1.02	1.05	1.06
	400	1.34	1.73	1.13	1.26	1.07	1.14	1.03	1.05	1.07
	500	1.36	1.76	1.14	1.28	1.07	1.15	1.03	1.05	1.07
	100	1.21	1.46	1.10	1.19	1.04	1.08	1.02	1.04	1.05
	200	1.28	1.60	1.11	1.23	1.05	1.11	1.03	1.05	1.07
3,000,000	300	1.31	1.67	1.13	1.26	1.06	1.11	1.03	1.06	1.08
	400	1.32	1.71	1.14	1.26	1.07	1.13	1.03	1.06	1.08
	500	1.33	1.73	1.14	1.26	1.07	1.13	1.03	1.06	1.08
	100	1.20	1.44	1.10	1.18	1.04	1.07	1.02	1.05	1.07
	200	1.24	1.55	1.11	1.21	1.04	1.09	1.03	1.05	1.07
2,000,000	300	1.29	1.62	1.12	1.23	1.05	1.10	1.03	1.07	1.07
	400	1.31	1.66	1.13	1.25	1.06	1.10	1.03	1.07	1.07
	500	1.32	1.69	1.13	1.26	1.06	1.11	1.04	1.07	1.08
	100	1.15	1.35	1.08	1.15	1.02	1.05	1.03	1.06	1.06
	200	1.22	1.48	1.10	1.19	1.03	1.06	1.04	1.07	1.07
1,000,000	300	1.25	1.56	1.11	1.22	1.04	1.07	1.04	1.08	1.07
	400	1.28	1.61	1.12	1.23	1.04	1.08	1.05	1.09	1.08
	500	1.29	1.64	1.12	1.24	1.04	1.08	1.05	1.09	1.08
	100	1.12	1.31	1.07	1.13	1.02	1.03	1.04	1.07	1.06
	200	1.20	1.46	1.09	1.18	1.02	1.04	1.05	1.09	1.07
500,000	300	1.23	1.55	1.10	1.20	1.03	1.05	1.05	1.11	1.09
	400	1.25	1.60	1.11	1.22	1.03	1.05	1.06	1.11	1.10
	500	1.27	1.63	1.11	1.23	1.03	1.05	1.06	1.12	1.11

To obtain the cost per cubic yard for the transport of the material under the conditions cited in the example above for a specific in situ density of 1500 grams per liter and slurry density of 1200 grams per liter, first refer to Figure 4-16. For a distance of 300,000 feet and from the curve reflecting a slurry density of 1200 grams per liter, the cost per cubic yard is $1.57. For an annual quantity of 2,000,000 cubic yards and the given combinations of distance and slurry density, the multiplier in the table on Figure 4-16 is 1.37. The "base" cost per cubic yard for this specific case is therefore $1.57 x 1.37 = $2.15. Next, the revised cost per cubic yard with the parameter values increased as specified in this example will be $2.15 x 1.62 = $3.48.

The results of the cost sensitivity analysis as shown in Table 4-6 are presented in graphic form in Figures 4-18 through 4-22 for seven select example combinations of variable values. Curve F on these graphs represents the worst case situation where the critical velocity and coefficient of friction are increased by 25%; energy and pipe laying costs are increased by 50%; and a redundant standby pump is provided for. It can be seen from these graphs that the worst case situation results in transportation costs which are nearly double the base case situation. It is believed that Curve F and the base case situation define a range within which actual centrifugal pumping system costs will fall. The precise costs associated with a centrifugal pumping system will, of course, be based upon the specific characteristics of each application. However, to provide a representative comparison with other transportation modes a "most probable" centrifugal pumping system is defined as an application requiring an increase in critical velocity over an optional situation of 20%, an increase in coefficient of friction of 10%, no increase in energy costs (to be comparable with other transportation modes), the utilization of redundant standby pumps, and an increase in pipe laying costs of 10%. The representative "most probable" case curve is also shown on these



Key:	Variable increase over "base" condition				
Curve	Critical Velocity	Coefficient of Friction	Energy Cost	Extra Standby Pump	Pipe Laying Cost
A	-	-	-	Yes	-
B	-	+50%	-	Yes	-
C	+25%	-	-	Yes	-
D	-	+50%	+50%	Yes	+50%
E	+25%	-	+50%	Yes	+50%
F	+25%	+25%	+50%	Yes	+50%
Most Probable Case	+20%	+10%	-	Yes	+10%

Figure 4-18. Cost Multiplier vs. Distance at an Annual Volume of 500,000 Cubic Yards

Key:	Variable increase over "base" condition				
Curve	Critical Velocity	Coefficient of Friction	Energy Cost	Extra Standby Pump	Pipe Laying Cost
A	-	-	-	Yes	-
B	-	+50%	-	Yes	-
C	+25%	-	-	Yes	-
D	-	+50%	+50%	Yes	+50%
E	+25%	-	+50%	Yes	+50%
F	+25%	+25%	+50%	Yes	+50%
Most Probable Case	+20%	+10%	-	Yes	+10%

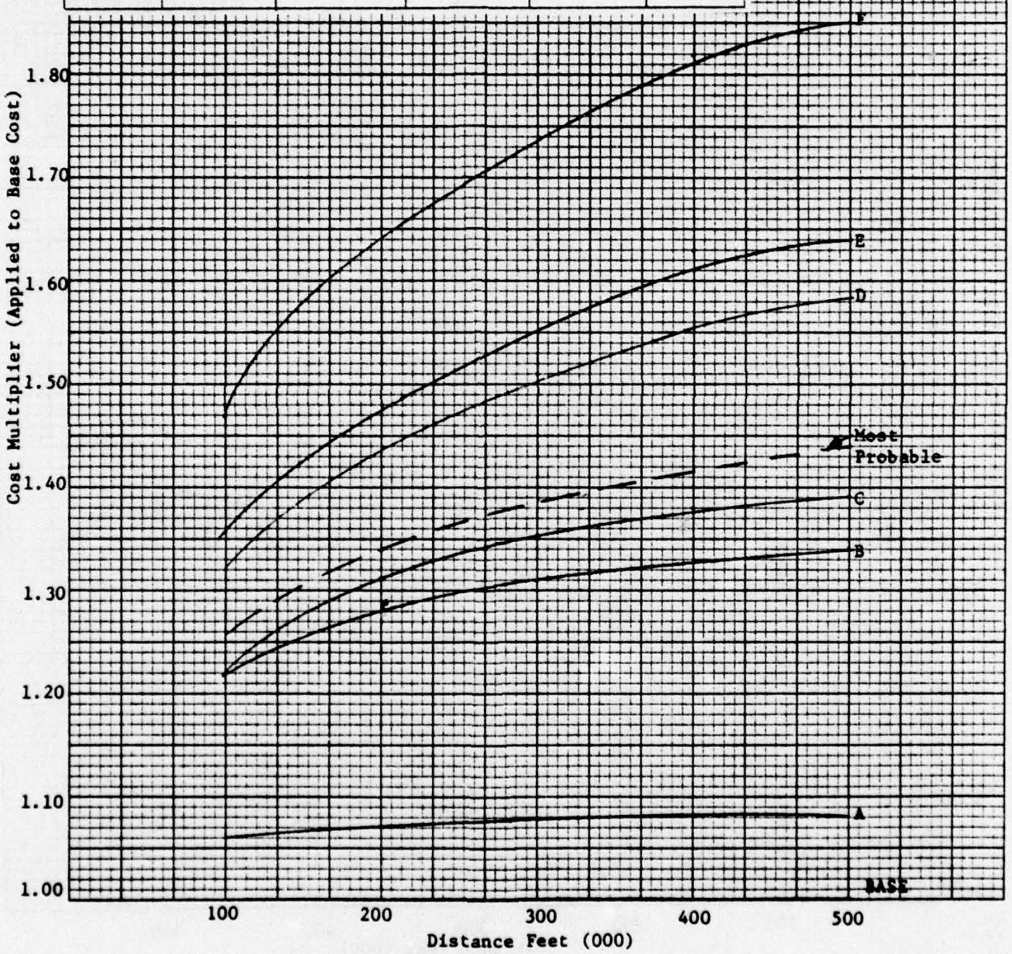
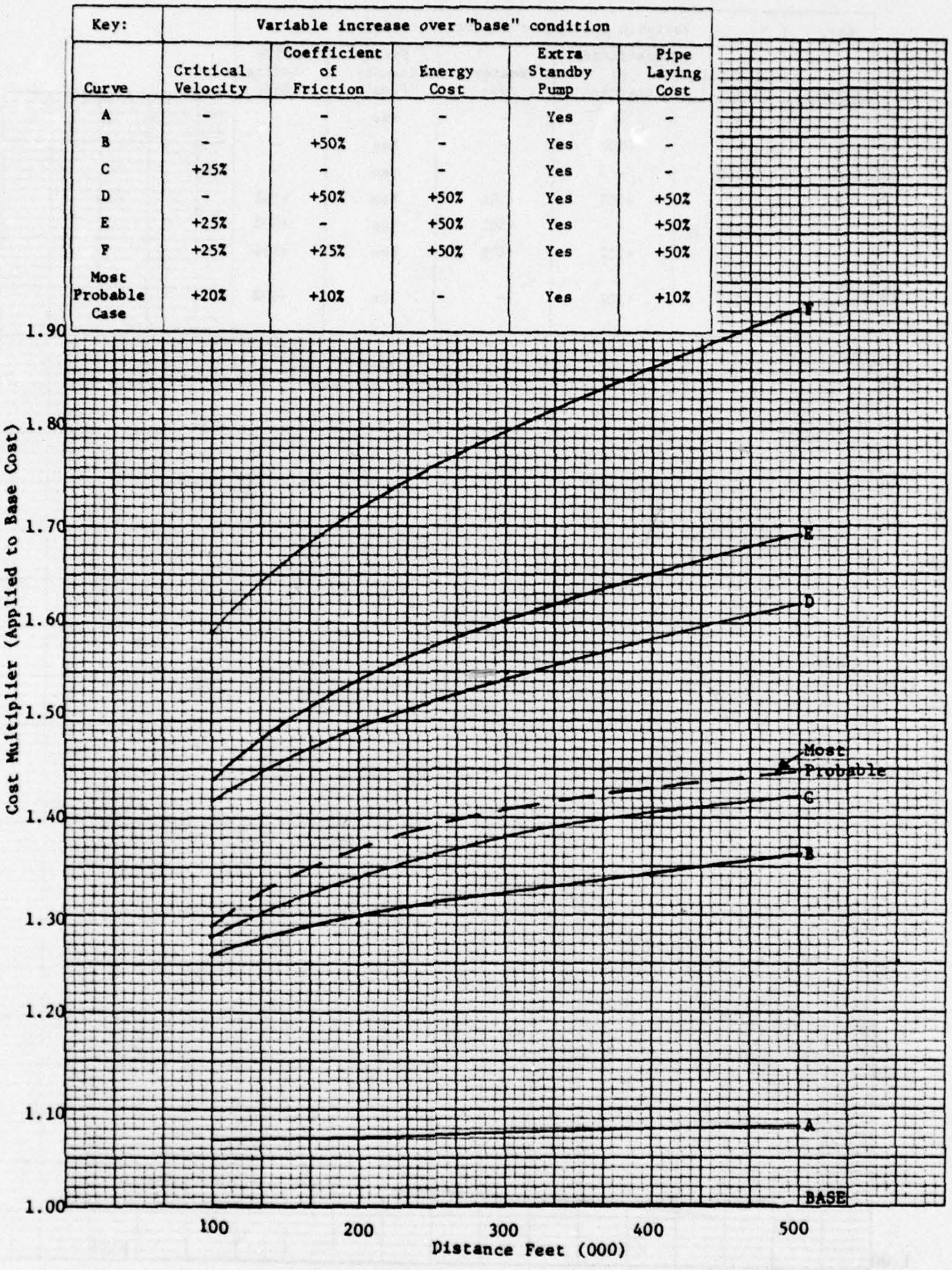


Figure 4-19. Cost Multiplier vs. Distance at an Annual Volume of 1,000,000 Cubic Yards



Key:	Variable increase over "base" condition				
Curve	Critical Velocity	Coefficient of Friction	Energy Cost	Extra Standby Pump	Pipe Laying Cost
A	-	-	-	Yes	-
B	-	+50%	-	Yes	-
C	+25%	-	-	Yes	-
D	-	+50%	+50%	Yes	+50%
E	+25%	-	+50%	Yes	+50%
F	+25%	+25%	+50%	Yes	+50%
Most Probable Case	+20%	+10%	-	Yes	+10%

Figure 4-20. Cost Multiplier vs. Distance at an Annual Volume of 2,000,000 Cubic Yards

Key:	Variable increase over "base" condition				
Curve	Critical Velocity	Coefficient of Friction	Energy Cost	Extra Standby Pump	Pipe Laying Cost
A	-	-	-	Yes	-
B	-	+50%	-	Yes	-
C	+25%	-	-	Yes	-
D	-	+50%	+50%	Yes	+50%
E	+25%	-	+50%	Yes	+50%
F	+25%	+25%	+50%	Yes	+50%
Most Probable Case	+20%	+10%	-	Yes	+10%

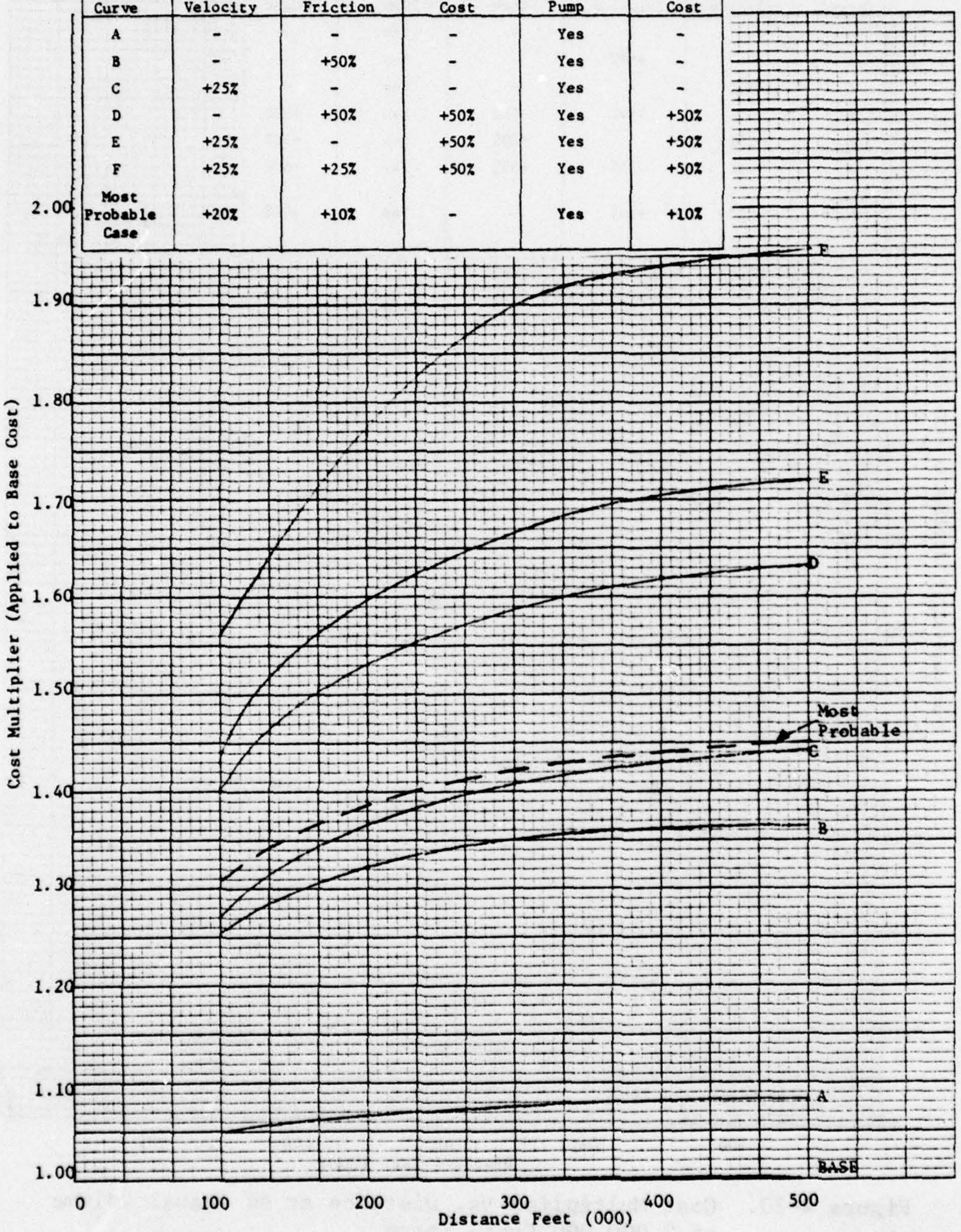
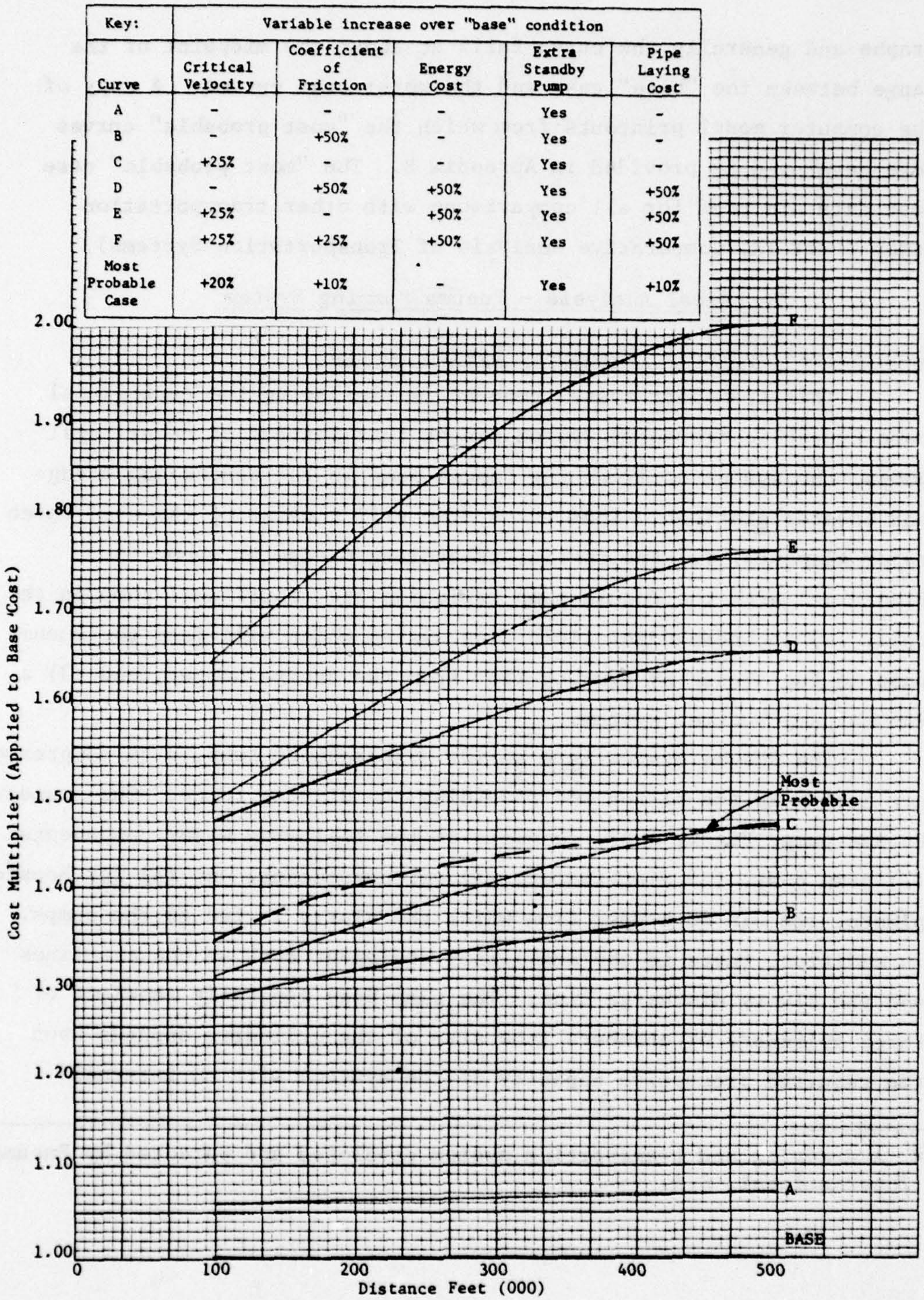


Figure 4-21. Cost Multiplier vs. Distance at an Annual Volume of 3,000,000 Cubic Yards



Key:	Variable increase over "base" condition				
Curve	Critical Velocity	Coefficient of Friction	Energy Cost	Extra Standby Pump	Pipe Laying Cost
A	-	-	-	Yes	-
B	-	+50%	-	Yes	-
C	+25%	-	-	Yes	
D	-	+50%	+50%	Yes	+50%
E	+25%	-	+50%	Yes	+50%
F	+25%	+25%	+50%	Yes	+50%
Most Probable Case	+20%	+10%	-	Yes	+10%

Figure 4-22. Cost Multiplier vs. Distance at an Annual Volume of 4,000,000 Cubic Yards

graphs and generally the curve falls at about the midpoint of the range between the "base" case and the worst case curves. A copy of the computer model printouts from which the "most probable" curves were developed is provided in Appendix B. The "most probable" case cost data are used for all comparisons with other transportation modes (Part IX, Comparative Analysis of Transportation Systems).

Technical Analysis - Pneuma Pumping System*

Generalized Hydraulic Transport System Concept

This transport system concept is similar to the centrifugal pump hydraulic transport system except that instead of centrifugal pumps, the system utilizes the Pneuma pump in the rehandling dredge and booster stations. Thus the system will consist of the same three major elements: (1) the special rehandling dredge as shown in Figure 4-1 with the Pneuma pump replacing the centrifugal pump in the hull, (2) an independent fluidizing system which will feed the Pneuma pump in the dredge by gravity flow from the dredge hopper, and (3) a Pneuma pump booster system.

The Pneuma system is a solids displacement pump, with compressed air acting as the piston and providing the driving force. The standard Pneuma pump, Figure 4-23, consists of the following major components: (1) pump body, (2) distributor, (3) air compressor, and (4) for booster plants, the bin or hopper from which the slurry is fed to the pumps. In addition, there is the auxilliary equipment such as the air lines and the slurry discharge line. The pump body generally consists of three cylinders or chambers (the size of the cylinders depends upon the required productive capacity of the system) with no internal

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* A dredging and transporting system developed and patented by Pneuma International, S.A.

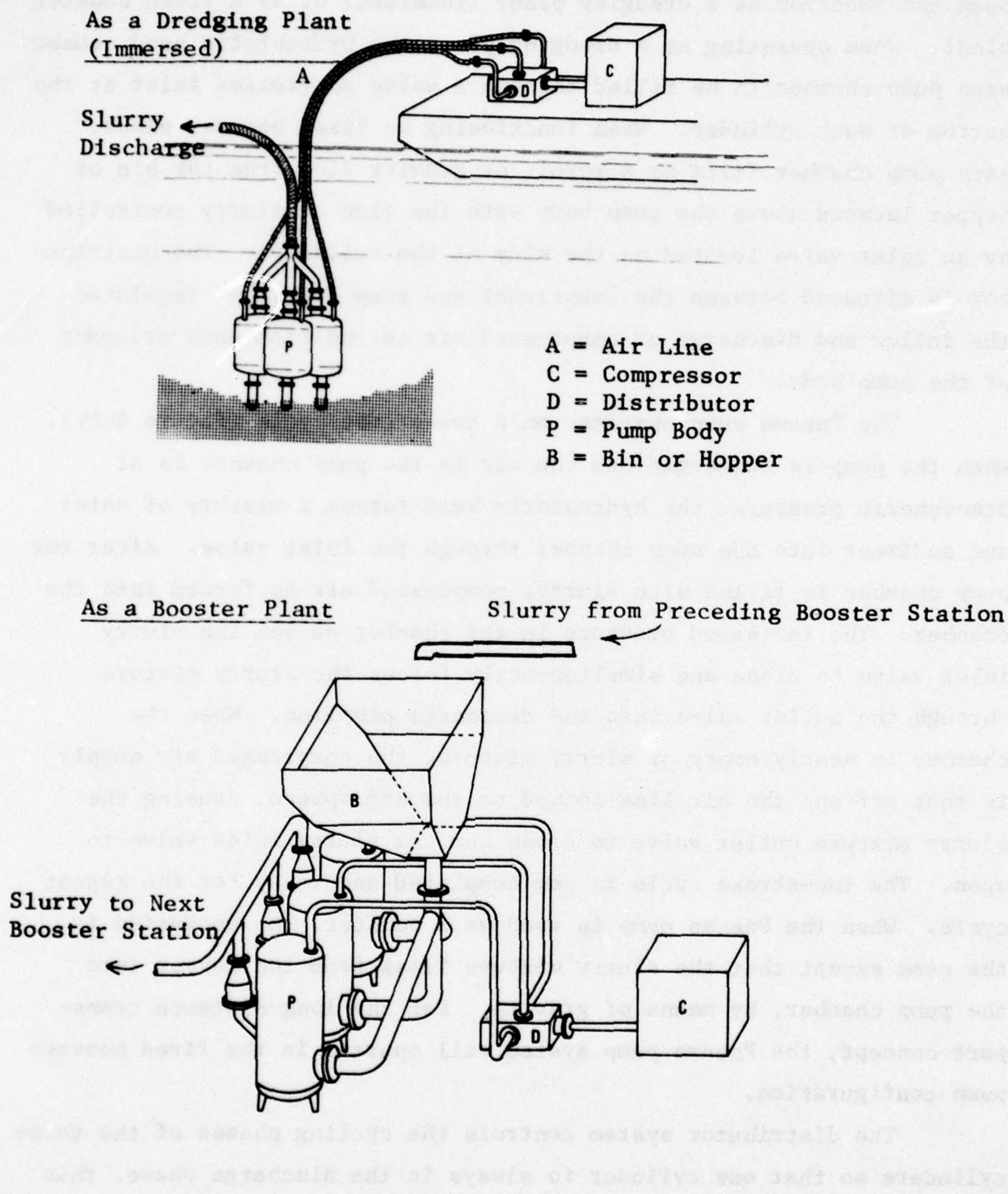

Figure 4-23. Pneuma Pump

rotating mechanisms except for rubber inlet and delivery valves. The pump can function as a dredging plant (immersed) or as a fixed booster plant. When operating as a dredging plant the hydrostatic head causes each pump chamber to be filled through a valve controlled inlet at the bottom of each cylinder. When functioning as fixed booster plant, each pump chamber fills as a result of gravity flow from the bin or hopper located above the pump body with the flow of slurry controlled by an inlet valve located on the side of the cylinders. The distributor is situated between the compressor and pump body. It regulates the inflow and discharge of compressed air to and from each cylinder of the pump body.

The Pneuma pump operates on a two-stroke cycle (Figure 4-24). When the pump is submerged and the air in the pump chamber is at atmospheric pressure, the hydrostatic head forces a mixture of water and sediment into the pump chamber through the inlet valve. After the pump chamber is filled with slurry, compressed air is forced into the chamber. The increased pressure in the chamber causes the slurry inlet valve to close and simultaneously forces the slurry mixture through the outlet valve into the discharge pipeline. When the chamber is nearly empty of slurry mixture, the compressed air supply is shut off and the air line opened to the atmosphere, causing the slurry mixture outlet valve to close and the slurry inlet valve to open. The two-stroke cycle is now completed and ready for the repeat cycle. When the Pneuma pump is used as a booster, the operation is the same except that the slurry mixture flows from the hopper into the pump chamber, by means of gravity. For the long-distance transport concept, the Pneuma pump system will operate in the fixed booster pump configuration.

The distributor system controls the cycling phases of the three cylinders so that one cylinder is always in the discharge phase, thus assuring a uniform and continuous flow. The distributor speed is

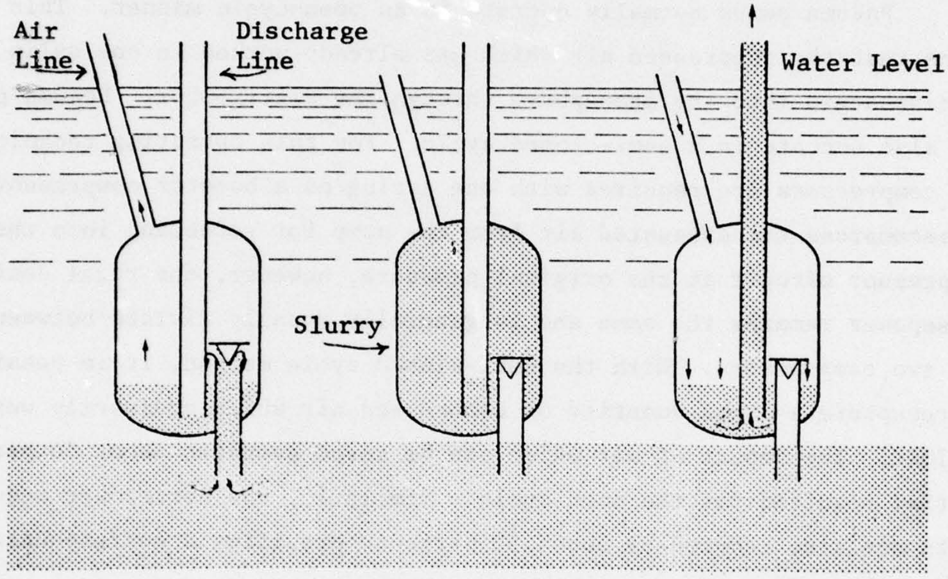

Figure 4-24. Pneuma Pump Operation

adjusted so that it opens and closes passages or ports, alternately, to the three pump chambers or to the atmosphere in such manner that uniform and steady flow in the discharge line is obtained. Depending on the particular job requirements, such as the quantity of slurry and pipeline velocity, there are usually one to three cycles per minute in the pump operation.

Pneuma pumps normally operate in an open-cycle manner. This means that the compressed air which has already worked in one cylinder is discharged into the atmosphere through the distributor. Penuma pumps can also operate in a semi-closed cycle. For this operating technique, two compressors are required with one acting as a booster compressor to recompress the exhausted air from the pump for refeeding into the compressor circuit at the original pressure; however, the total design horsepower remains the same and is generally equally divided between the two compressors. With the semi-closed cycle method, it is possible to recapture a large quantity of compressed air which ordinarily would be lost. The amount of air which can be saved averages about 50 percent of that required for the open cycle. Similarly, the horsepower requirements are also reduced by about 50 percent, providing a corresponding savings in energy costs.

The Pneuma pump body has no mechanically driven parts and, as a result, maintenance costs due to wear are minimal. Pneuma pump systems usually operate under air pressures of six to eight atmospheres, where average pipeline distances are involved. However, for the long-distance transport concept, economic considerations dictate maximum possible spacing between booster stations. For this purpose, an operating air pressure of 11 atmospheres is practical and realistic and provides for booster station spacing of over 17,000 feet.

The rehandling dredge and the independent fluidizing system for the Pneuma pumping system are similar to that previously described for the centrifugal pumping system except that the Pneuma pump is substituted for the centrifugal pump in the rehandling dredge. The

water supply system is of the centrifugal type and serves the dual purpose of providing water for dredge flotation and the fluidizing system as well as providing the water to clear the entire length of pipeline in the event of a breakdown of the dredge pumping plant.

The Pneuma pump booster system consists of a series of identical booster stations spaced uniformly from the dredge to the far distant disposal area. The booster plant consists of a steel hopper or bin of about 100 cubic yard capacity (to receive the slurry from the preceding station), necessary air compressors of the semi-portable type, and the distributor. The equipment is supported on a concrete slab. The entire installation is housed within a corrugated sheet metal building of minimum size and cost.

As a design concept, for purposes of minimizing possible blockage of the system because of a malfunction of one of the booster units, a small water supply reservoir, having a capacity of about 500 cubic yards, is incorporated at each booster station to permit the clearing of the pipeline of slurry. The entire booster station is enclosed with a cyclone fence as a safety precaution and to provide some degree of security. Similar to the centrifugal pump system, the Pneuma system is automated to the maximum extent feasible, with primary control being at the rehandling dredge.

Detailed Design for the Transport of Dredged Material Inland

Pneuma pumps are manufactured in different sizes so that a wide range of capacities is available to satisfy the production requirements for specific conditions. Table 4-7 shows the capacities of different types of Pneuma pumps for maintenance type material generally of the smaller particle size. (Note: Slurry discharge capacity in cubic yards per year is based on the system being in operation six days per week, 24 hours per day with an operational effectiveness of 90 percent, equating to 280 days per year.)

Table 4-7

Pneuma Pump Capacities (Slurry Discharge)

Pump Type*	Pipe Diameter	Slurry Discharge Capacity Cubic Yards/Hour	Cubic Yards/Year
150/30	8"	170	1,140,000
300/60	10"	350	2,350,000
450/80	12"	590	3,960,000
600/100	14"	930	6,250,000

*Type designation by Pneuma S.P.A.

Pneuma pumps, because of their pistonlike action, have the capability of pumping slurry mixtures of very high solids concentration. When the pump is used in dredging operations (submerged), the inlet or intake velocity depends upon the hydrostatic head. The density of the material or slurry entering the pump is a factor of inlet velocities, physical characteristics of the bottom material, and the effectiveness of operational controls. Generally, in dredging operations, percentages of solids of up to 60 to 80 percent in volume of the in situ density material are capable of being achieved. On the other hand, if the in situ material is fluidized in a hopper such as will be the case with the rehandling dredge, the mixture pumped by the dredge will be at the fluidized slurry density since the pumps will be gravity fed. With the controls to be exercised in the fluidizing process at the dredge, the percentages of solids in the mixture of up to 95 percent in volume of the in situ material would be possible. The term "percentage of solids" indicated above will hereafter be referred to as the "efficiency factor" and is defined as the ratio of solids in the slurry to the solids in the in situ material per unit of volume.

For purposes of developing the design and cost for the Pneuma pump system, an efficiency factor of 0.90 is considered to be realistic and will be used in subsequent computations. On the basis of this 0.90 efficiency factor, the slurry discharge capacities in Table 4-7 are converted to disposal area production capacities as shown in Table 4-8. Based upon these disposal area production capacities, Table 4-9 was developed which shows the percent operating time required for disposal area production capacities in cubic yards per year of 500,000, 1,000,000, 2,000,000, 3,000,000, and 4,000,000 for the different type Pneuma pumps as applicable.

Table 4-8

Pneuma Pump Capacities (Disposal Area Production)

Pump Type	Disposal Area Production: Cubic Yards per Year	Disposal Area Production: Cubic Yards per Hour
150/30	1,020,000	153
300/60	2,110,000	315
450/80	3,560,000	531
600/100	5,620,000	837

Table 4-9

Percent Operating Time for Variable Disposal Area Production

Pump Type	Percent Operating Time for Disposal Area Production, Cubic Yard: 500,000	1,000,000	2,000,000	3,000,000	4,000,000
150/30	49	98	-	-	-
300/60	24	47	95	-	-
450/80	14	28	56	84	-
600/100	9	18	36	53	71

The Pneuma S.P.A., Florence, Italy, has published an operations and performance manual, "Pneuma System,"[7] which contains charts, curves, and formulas depicting horsepower and volumetric compressed air requirements for variable pumping distances and air pressures. Although the data are extensive, they relate only to specific conditions of in situ and slurry densities and, therefore, could not be readily adapted to conditions of varying densities. However, by utilizing the performance data of the curves and applying basic engineering theory with respect to hydraulic flow and the relationship between compressed air requirements and horsepower, it was possible to develop basic curves, Figures 4-25 and 4-26, which provide the necessary data to design Pneuma pump systems under varying efficiency factors and conditions of in situ densities for both the open and semi-closed cycles.

Tables 4-10 and 4-11 give for the open and semi-closed cycles the respective horsepower and compressed air requirements for different type pumps for an air pressure of 11 atmospheres and a booster station spacing of 17,000 feet. These two tables give the basic design elements for any Pneuma system under the specified conditions. However, as a safety and contingency factor, similar to that provided for in the centrifugal pump system where the booster station spacing was reduced 10 percent, the theoretical horsepower requirements for the Pneuma system in Tables 4-10 and 4-11 will be increased about 10 percent and the air pressure to be developed increased from the theoretical 11 atmospheres to 12 atmospheres. Thus, an approximate 10-percent overload will be available in the system.

Cost Analysis - Pneuma Pumping System

Cost Derivation

Similar to the cost data developed for the centrifugal pumping system, the cost data derived hereafter for the Pneuma pumping system is on the basis that the system would be constructed by the Government but be contractor operated, with full operation considered to be 24 hours

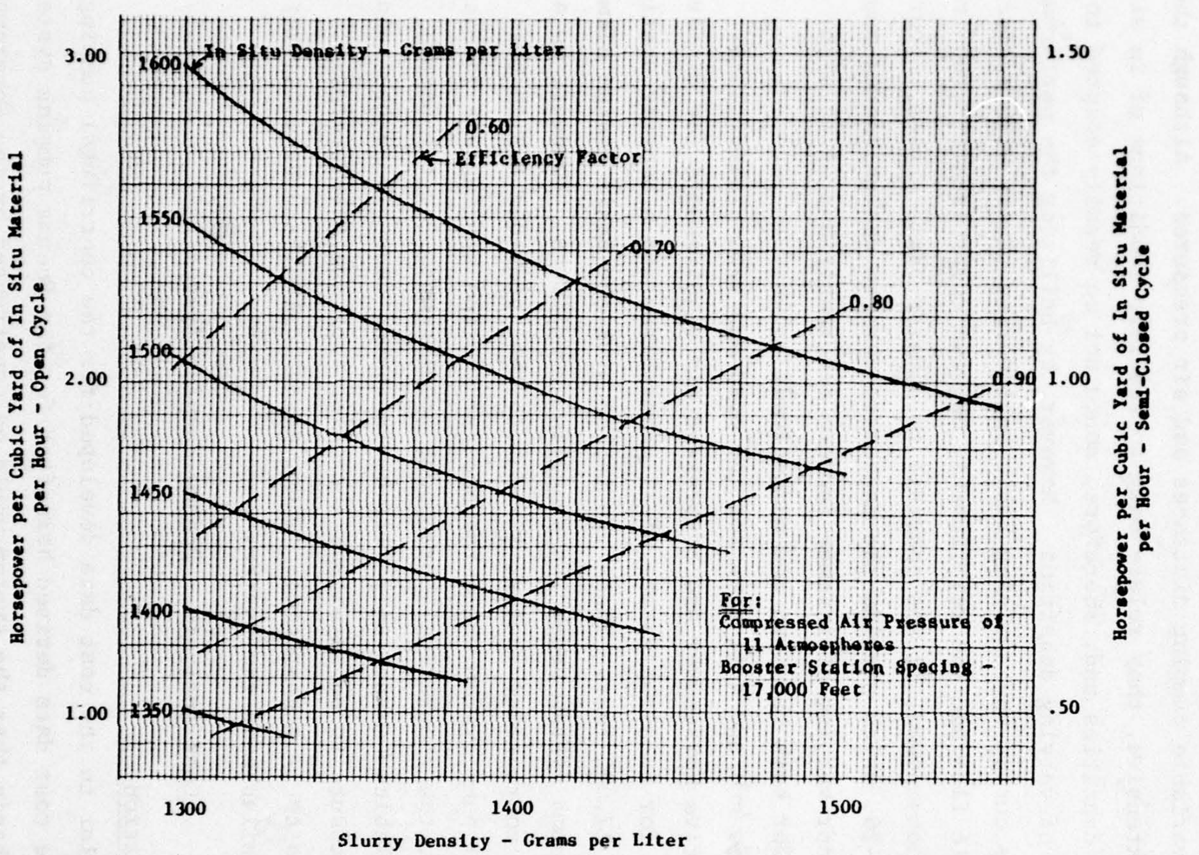

Figure 4-25. Pneuma Pump -Horsepower Requirements per Cubic Yard of In Situ Material per Hour for Variable Conditions of Slurry and In Situ Densities (for Both Open and Semi-Closed Cycles)

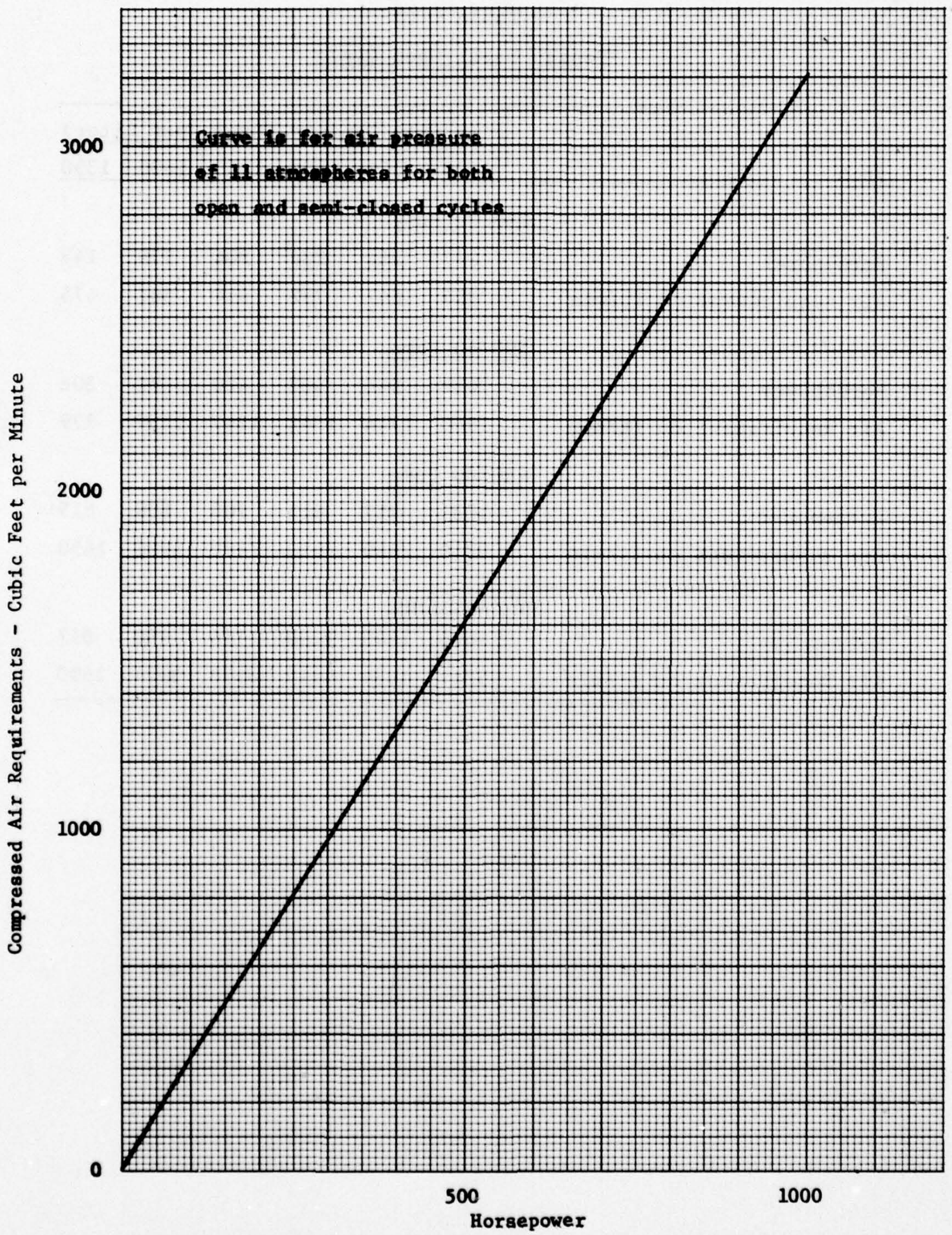

Figure 4-26. Compressed Air Requirements Versus Horsepower

Table 4-10

Design Data, Open Cycle

Item	In Situ Density (Grams per Liter) 1600	1550	1500	1450	1400	1350
150/30 Pump						
Horsepower	297	264	234	204	175	148
Air Requirement cu ft/min	954	847	752	654	562	475
300/60 Pump						
Horsepower	612	544	482	420	361	306
Air Requirement cu ft/min	1960	1744	1548	1347	1157	979
450/80 Pump						
Horsepower	1031	917	812	708	609	515
Air Requirement cu ft/min	3310	2940	2610	2270	1950	1650
600/100 Pump						
Horsepower	1625	1445	1280	1116	960	812
Air Requirement cu ft/min	5217	4634	4115	3578	3074	2600

Table 4-11

Design Data, Semi-Closed Cycle

Item	In Situ Density (Grams per Liter)					
	1600	1550	1500	1450	1400	1350
150/30 Pump						
Horsepower	149	132	117	102	88	74
Air Requirement cu ft/min	477	424	376	327	281	238
300/60 Pump						
Horsepower	306	272	241	210	180	153
Air Requirement cu ft/min	980	872	774	674	578	490
450/80 Pump						
Horsepower	516	459	406	354	305	258
Air Requirement cu ft/min	1655	1470	1305	1135	975	825
600/100 Pump						
Horsepower	813	724	640	558	480	406
Air Requirement cu ft/min	2609	2317	2058	1789	1537	1300

per day, six days per week, and an effective 280 days per year. The cost derivations for each of the major elements of the Pneuma pumping system are discussed and outlined below.

Booster Station Costs

Table 4-12 presents the costs of a booster station for the different type Pneuma pumps and variable horsepower requirements of both the open and semi-closed cycles. The booster station spacing for all conditions is fixed at 17,000 feet. The horsepower shown in the table is the theoretically derived requirement; however, the cost data include an adjustment to provide for the approximately 10 percent increase in horsepower and air pressure as previously discussed. The cost data cover the Pneuma pump and auxilliary equipment, distributor, air hoses, air compressors and electric motors, reduction gears, control equipment, foundation, housing, fencing, water supply reservoir, provisions for cooling water, installation and allowances for maintenance and repair, insurance, and such other miscellaneous costs as applicable. All first costs are reduced to annual amounts on a capital recovery basis for a 20-year life at 7 percent interest. For the semi-closed cycle, the cost data cover the booster compressor and the more complex distributor system, in addition to the items indicated above.

Booster Station Labor Costs

The booster station labor costs per full year of operation based on a roving patrol of one man per shift for each five booster stations and including allowances for fringe benefits, necessary transportation, and contractor overhead and fee is the same as for the centrifugal pump system: \$120,000 for five stations (5 x 17,000 = 85,000 feet). The annual labor cost per 1000 feet of pipeline for any operation equals \$120,000 divided by 85 multiplied by percent of operating time divided by 100.

$$\text{Booster labor cost per year per 1000 feet} = \frac{\$120{,}000 \times \text{percent operating time}}{8500}$$

Table 4-12

Annual Cost per Booster Station
(In Dollars)

Horsepower Requirement	Type Pump							
	Open Cycle				Semi-Closed Cycle			
	150/30	300/60	450/80	600/100	150/30	300/60	450/80	600/100
50					35,300			
100					39,900			
150	30,400				43,300	44,800		
200	33,600					48,200		
250	35,800					51,600	53,000	
300	38,100	39,300				54,800	56,200	
400		43,900				60,400	61,800	62,900
500		48,700	49,900				67,200	68,300
600		53,200	54,400				71,800	72,900
700		58,100	59,300					77,500
800			63,800	54,700				82,100
900			68,400	69,300				86,900
1000			73,200	74,100				
1200			97,300	98,200				
1400				107,600				
1600				117,000				
1700				121,600				

Pipeline Costs

The pipeline costs shown in Table 4-3 for the centrifugal pump system are applicable to the Pneuma pump system without change.

Energy Costs

Table 4-13 presents the energy costs per 1000 feet of pipeline per full year operation for variable conditions of horsepower. The unit rate for electrical energy has been assumed as \$0.021 per kilowatt hour, this figure being the countrywide average as of July 1976. The table was derived from the formula:

$$\text{Energy cost per 1000 feet per full year operation (in dollars)} = \frac{0.021 \times \text{horsepower} \times 24 \times 280 \times 0.746}{17}$$

$$= 6.1927 \times \text{horsepower}$$

Note: Where the system is operated less than full time (280 days per year), the energy costs shown in the table should be multiplied by the percent operating time divided by 100.

Rehandling Dredge Costs

The cost derivation for the rehandling dredge for the Pneuma system is on the same basis as that for the centrifugal pump system. The substitution of a Pneuma pump for the centrifugal pump in the basic dredge has only a negligible effect on the overall dredge cost. Consequently, the annual costs for the rehandling dredge shown in Table 4-4 are applicable to the Pneuma system for the size dredge (pipeline diameter) equivalent to that for the specific Pneuma pump type (Table 4-7).

Rehandling Dredge Labor Costs

The rehandling dredge labor costs per full year operation are identical to those for the centrifugal pump system. Thus, the costs shown in Figure 4-11 are applicable, and for any operation the annual cost would be the total annual cost per full year operation (\$900,000) multiplied by the percent operating time divided by 100.

Table 4-13

Annual Energy Cost Per 1000 Feet of Pipeline

Horsepower	Annual Cost
100	$ 620
200	1,240
300	1,860
400	2,480
500	3,100
600	3,720
700	4,340
800	4,960
900	5,580
1000	6,190
1200	7,430
1400	8,670
1600	9,910
1800	11,150

Illustrative Example of Design Determination and Costing

To illustrate how the previously developed figures and tables can be used to design a long distance Pneuma transport system for a specific set of conditions and to estimate its costs, the following step-by-step procedure is presented.

Given conditions.

Density of water - 1000 grams/liter

Density of disposal area material - 1600 grams/liter

Density of slurry (efficiency factor 90 percent) - 1540 grams/liter

Annual quantity of material to be removed from disposal area - 2,000,000 cubic yards/year

Pneuma pump type - 450/80

Cycle - Open

Pressure of compressed air - 11 atmospheres

Booster station spacing - 17,000 feet

Theoretical life of pipe - 8 years

Pipe diameter - 12 inches

Percent operating time. From Table 4-9 the percent operating time for a disposal area production of 2,000,000 cubic yards per year utilizing a 450/80 Pneuma pump is 56 percent.

Horsepower and compressed air requirements. From Table 4-10 the horsepower requirement for disposal area material having an in situ density of 1600 grams per liter using a 450/80 Pneuma pump is 1031 and the compressed air requirement is 3310 cubic feet per minute.

Booster station costs. From Table 4-12 the booster station cost per year for 1031 horsepower for the 450/80 Pneuma pump is:

$$(\$97{,}300 - 73{,}200) \times \frac{31}{200} + 73{,}200 = \$76{,}800$$

The cost per booster station per 1000 feet per year is:

$$\frac{\$76{,}800}{17} = \$4{,}520.$$

Booster station labor cost. From the previously derived cost data for this item, the booster station labor cost per 1000 feet of pipeline per year equals $120,000/85 multiplied by the percent operating time, divided by 100 = 120,000/85 x 56/100 = $790.

Pipeline costs. From Table 4-3, the annual pipeline cost per 1000 feet of 12-inch diameter pipe having an effective life of 14 years (8/0.56) is $2700.

Energy costs. From Table 4-13, the energy cost per 1000 feet of pipeline per year is 0.56 x 6.1927 x 1031 = $3570.

Rehandling dredge costs. From Table 4-4, the annual cost for a rehandling dredge having a 12-inch pipeline system (450/80 Pneuma pump) is $450,000.

Rehandling dredge labor cost. From the previously developed data, the annual dredge labor cost equals $900,000 multiplied by the percent operating time divided by 100 = $900,000 x 56/100 = $504,000.

The above data are consolidated and costs computed for variable pipeline distances. For simplicity, the distances used are in multiples of 100,000 feet. A summary sheet, Table 4-14, depicts both the design and cost data for the given conditions of the above illustrative example.

Summary Costs for Pneuma Pumping System

The illustrative example is for only one set of conditions, its purpose being to demonstrate the step-by-step procedure to be followed in developing design and cost data for a particular set of conditions. For planning purposes and for approximate comparative analysis of costs for different sets of conditions wherein in situ densities, annual quantities to be handled, and pipeline distances vary, groups or families of curves would be required. Similar to the procedure followed for the centrifugal pumping system, summary design and cost data sheets in the format of Table 4-14 were developed for in situ densities of 1400, 1500, and 1600 grams per liter; annual quantities varying from 500,000 to 4,000,000 cubic yards; distances varying from 100,000 to 500,000 feet;

Table 4-14

Illustrative Example - Design and Cost Data Summary

(Pump 450/80, Open Cycle, Air Pressure 11 Atmospheres, Booster Station Spacing 17,000 feet, In Situ Material Density 1600 Grams per Liter)

Item	Disposal Area Production, Cubic Yards per Year			
	500,000	1,000,000	2,000,000	3,000,000
Horsepower (theoretical)			1,031	
Air requirement, cubic feet per minute			3,310	
Percent operating time			56	
Pipeline diameter, inches			12	
Pipeline life (effective) years			14	
Booster station cost per 1000 feet per year			$4,520	
Booster station labor cost per 1000 feet per year			$790	
Pipeline cost per 1000 feet per year			$2,700	
Energy cost per 1000 feet per year			$3,570	
Subtotal			$11,580	
Rehandling dredge cost per year			$450,000	
Rehandling dredge labor cost per year			$504,000	
Subtotal			$954,000	
Cost for:				
100,000 feet			$2,112,000 (1.06)*	
200,000 feet			$3,270,000 (1.64)	
300,000 feet			$4,428,000 (2.21)	
400,000 feet			$5,586,000 (2.79)	
500,000 feet			$6,744,000 (3.37)	

*Numbers in parentheses are dollars per cubic yard.

and an average life of pipe commensurate with the type material to be pumped and the flow velocities generally associated with Pneuma systems. All computations were made for each type of Pneuma pump which had the capacity to meet the particular production requirements, thus assuring that the most cost effective system was obtained.

From these data sheets two comprehensive charts were prepared, Figures 4-27 and 4-28, which present the least cost for open and semi-closed cycle Pneuma transport systems, respectively, for any desired set of conditions. These cost curves are based on an annual quantity of 4,000,000 cubic yards. However, the adjacent table on each figure provides the multiplying factors for the varying conditions. The cost curves are on the basis of cost per cubic yard as well as cost per cubic yard per mile.

An examination of Figures 4-27 and 4-28 indicates that the semi-closed cycle Pneuma system is the most cost effective for annual quantities in excess of 500,000 cubic yards. However, it does appear that for annual quantities of a lesser amount and for the lower range of in situ densities, the open cycle system is probably the more economical.

It should be noted that the cost data developed for the Pneuma system are on the same basis as that for the centrifugal system; that is, no costs for rights-of-way, real estate, or disposal areas are included.

<u>Cost Comparison of Centrifugal versus Pneuma Transport System</u>

Both the centrifugal transport system and the Pneuma transport system are technically feasible hydraulic means for transporting dredged material over long distances. The cost effectiveness of either system will depend on the particular conditions upon which the design is based. It is apparent from an examination of the base cost data charts for both systems, under the varying conditions depicted, that depending on the specific conditions, either system could be the most cost effective. As an example, Figure 4-29 was developed to

Annual Quantity cu yds	Pipeline Distance (000 ft)	Multiplier: In situ density 1400	1500	1600
4,000,000	100			
	200			
	300		1.00	
	400			
	500			
3,000,000	100	1.16	1.16	1.15
	200	1.16	1.14	1.13
	300	1.16	1.12	1.11
	400	1.16	1.11	1.09
	500	1.16	1.10	1.08
2,000,000	100	1.44	1.42	1.40
	200	1.43	1.36	1.34
	300	1.43	1.33	1.31
	400	1.41	1.32	1.29
	500	1.40	1.30	1.28
1,000,000	100	2.23	2.10	2.09
	200	2.15	2.00	1.93
	300	2.12	1.94	1.85
	400	2.09	1.90	1.81
	500	2.07	1.87	1.78
500,000	100	3.64	3.38	3.20
	200	3.43	3.12	2.98
	300	3.34	3.01	2.86
	400	3.27	2.95	2.78
	500	3.22	2.90	2.70

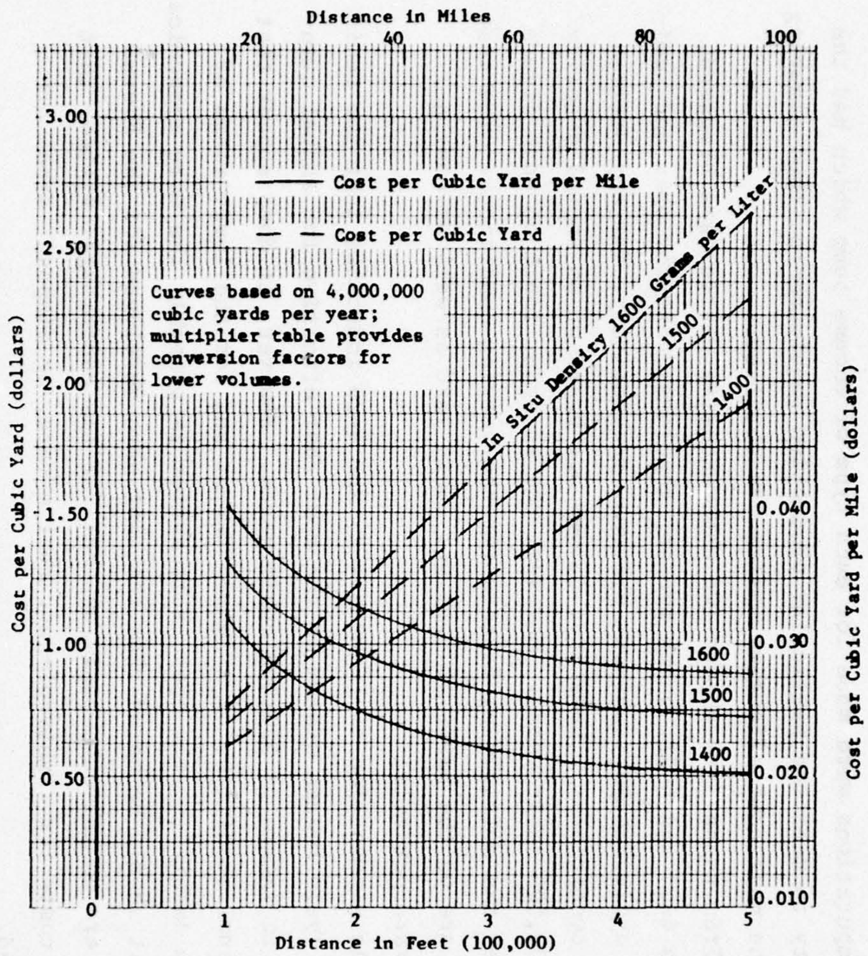

Figure 4-27. Cost of a Pneuma Pump (Open Cycle) Transport System for Variable In Situ Densities

Annual Quantity cu yds	Pipeline Distance (000 ft)	Multiplier In situ density 1400	1500	1600
4,000,000	100	1.00		
	200			
	300			
	400			
	500			
3,000,000	100	1.18	1.17	1.17
	200	1.18	1.17	1.17
	300	1.18	1.17	1.17
	400	1.18	1.17	1.17
	500	1.18	1.17	1.17
2,000,000	100	1.48	1.47	1.46
	200	1.48	1.47	1.46
	300	1.48	1.47	1.46
	400	1.48	1.47	1.46
	500	1.48	1.47	1.46
1,000,000	100	2.40	2.36	2.33
	200	2.35	2.31	2.28
	300	2.35	2.31	2.27
	400	2.34	2.30	2.25
	500	2.33	2.29	2.24
500,000	100	4.04	3.95	3.87
	200	3.92	3.81	3.71
	300	3.90	3.76	3.67
	400	3.85	3.75	3.62
	500	3.82	3.71	3.60

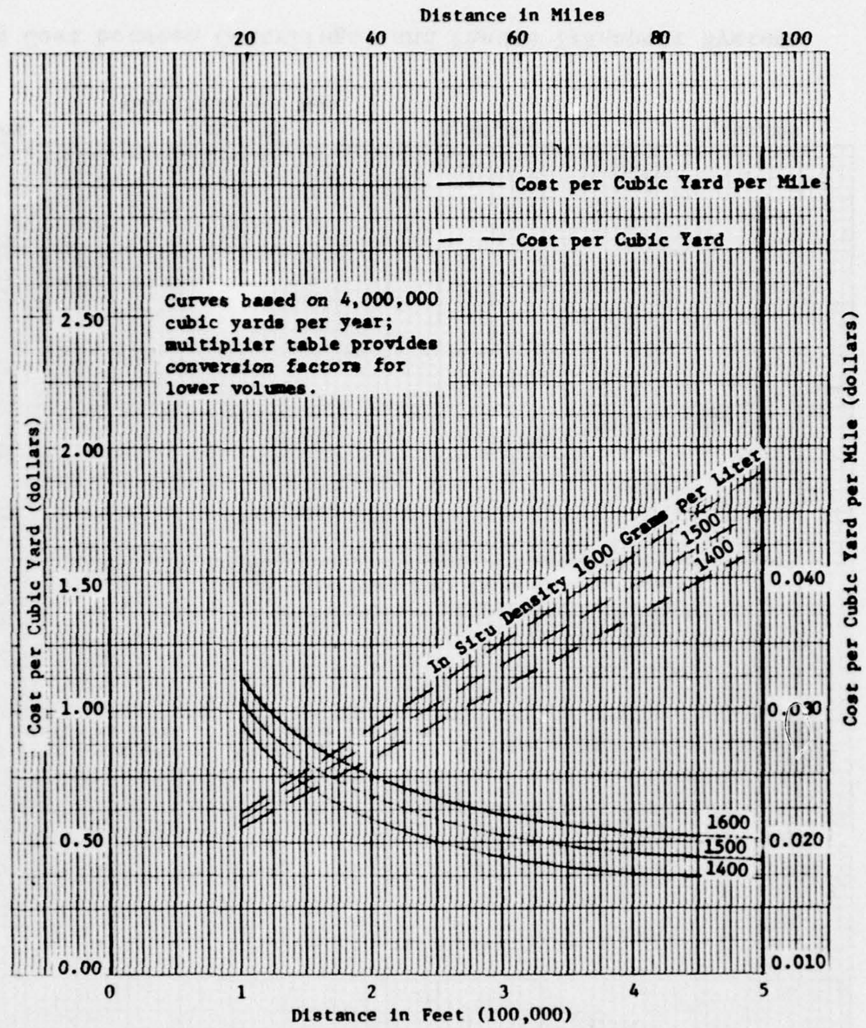

Figure 4-28. Cost of a Pneuma Pump (Semi-Closed Cycle) Transport System for Variable In-Situ Densities

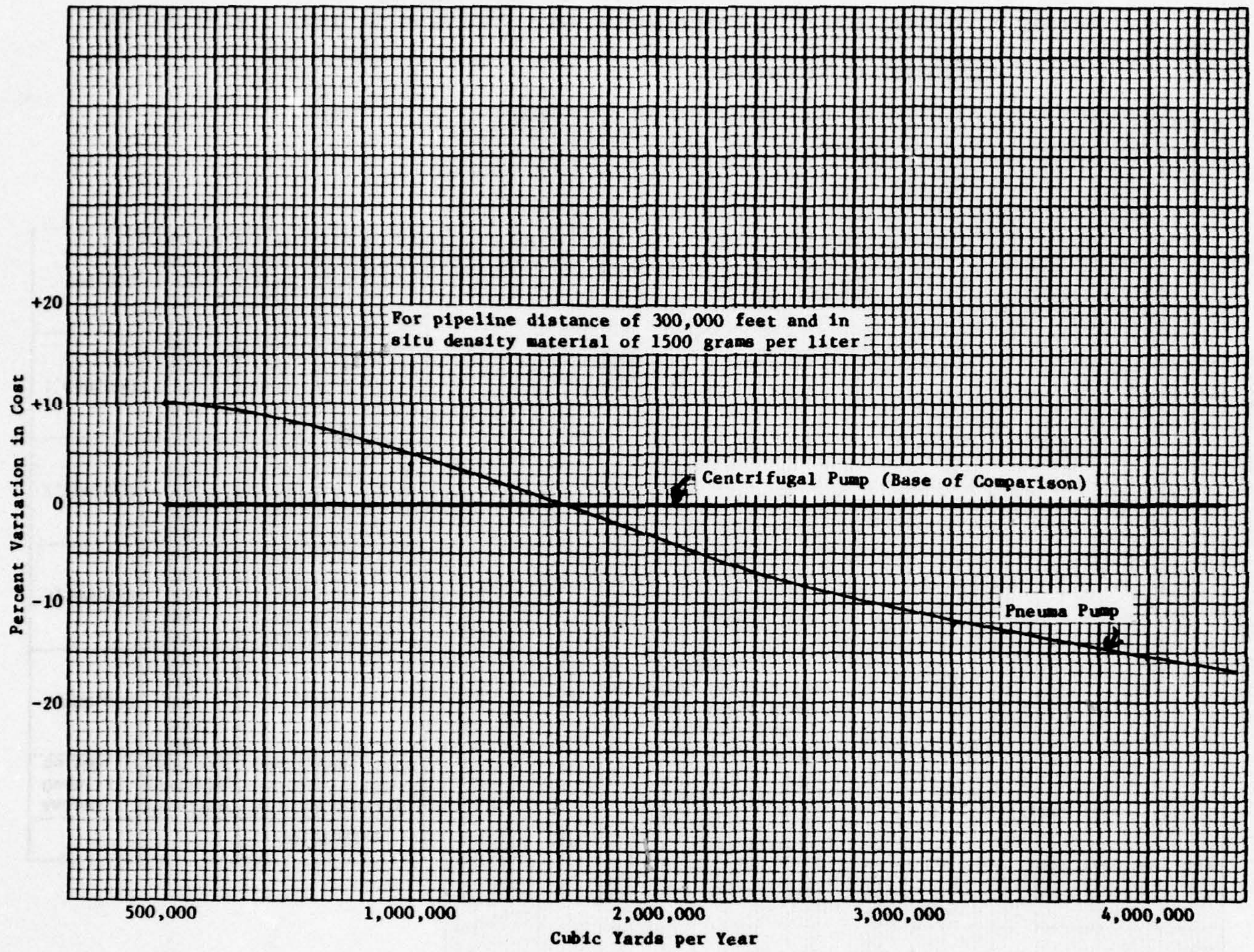

Figure 4-29. Variation in Cost between Centrifugal and Pneuma Transport Systems

depict the base cost comparison between a centrifugal system and a Pneuma system for a given set of conditions but for varying annual production quantities. The chart is for a fixed pipeline distance of 300,000 feet and an in situ density of disposal area material of 1500 grams per liter. The curve for the centrifugal system is for an average slurry density. This chart of comparative costs indicates that for the above conditions the two systems appear to be competitive; therefore, it is recommended both hydraulic transport systems be investigated to determine the most cost effective system for a given application. It should be noted that no sensitivity analysis was conducted for the Pneuma system; however, the costs developed for each system are based on the most favorable design conditions. It is believed that for purposes of cost comparisons the costs associated with less favorable conditions for the Pneuma system will follow the same pattern as found for the centrifugal pumping systems.

Additional Pipeline Slurry Considerations

The following considerations should be examined prior to the selection of hydraulic pipeline transport as the desired transportation alternative.

Disposal of Effluent

In the case of pipelining dredged material to inland disposal areas, a severe environmental problem may be encountered with the disposal of the water effluent from the slurry mixture which may be saline and/or not meet clean water standards. This problem was considered in the study of alternative methods of disposal of dredged material from Craney Island, Norfolk, Virginia:[8]

> "Two major environmental considerations of the Nansemond site (Nansemond County, Va.) deal with the effects saltwater drainage and seepage could have on the surrounding area. The problem of what to do with drainage runoff from spoil is of paramount importance. Two preliminary plans have been considered: (1) to collect and drain the water

by culverts into the Nansemond River and (2) to return the runoff to Craney Island by the same pipeline mechanism used to transport to the Nansemond site. Substantive knowledge of the quality of this saltwater and its influence after deposition, particularly on the salinity and water quality of the river, is a 'must' in order to more accurately predict an overall environmental impact. Also, the potential for serious damage to native ground-water supplies by saltwater seepage has been recognized. Knowledge of location, extent, and direction of these supplies, and possible means for preventing damage from seepage is likewise of paramount importance. An extensive network of research (test) wells in the Nansemond site would likely be required before this question could be resolved."

This problem was also considered in the study of land disposal, San Francisco Bay:[9]

> "An inland site could require a discharge pipeline and possibly a pumping system to return decanted water to an acceptable discharge location (the most desirable site would be immediately adjacent to a body of water which could accept the discharge, subject to the effluent meeting turbidity, salinity, and pollutant criteria by regulating agencies)."

Environmental Groups and the Public

Another potential problem pointed out in the Final Environmental Statement for Diked Disposal Island, Hart and Miller Islands, Baltimore County,[10] is the pressure which might be encountered from environmental groups and the public, particularly since the dangers of pollution from a fractured or leaking pipeline are yet to be resolved.

> "With the increased length of pipeline and greater number of booster stations, the danger of leakage is increased, necessitating protection safeguards."

Routing the Pipeline

Consideration must also be given to the many factors which would have to be dealt with in the routing of the pipeline. These include obtaining rights-of-way, disruptions caused by construction of a pipeline through urban areas, and difficulties of land terrain encountered.

A major legal consideration in pipeline transportation is obtaining the rights-of-way necessary for construction of the pipeline. A portion of the general requirements for local cooperation on Corps of Engineers' projects by non-Federal interests is provided below:

> "Provide without cost to the United States all lands, easements, right-of-way, and relocations necessary for the construction, and subsequent operation and maintenance of the project including suitable areas determined by the Chief of Engineers to be required in the general public interest for initial and subsequent disposal of spoil and necessary retaining dikes, bulkheads, and embankments therefor, or the costs of such retaining works. Accomplish without cost to the United States all alterations and relocations of highway bridges, buildings, streets, storm drains, utilities, and other structures and improvements.
>
> For authorized projects, the documents in support of the acts authorizing or modifying the projects contain the authority for requiring local cooperation. Specific details of required local cooperation for projects under continuing authorities are contained in the reports and approvals authorizing the work. The pre-authorization report includes a copy of a letter of intent to cooperate from the responsible project sponsor. Formal binding assurances are obtained prior to commencement of construction.... No construction is undertaken until satisfactory assurances are in hand concerning all required cooperation by a qualified local sponsor and until lands, easements, and rights-of-way for a complete unit of the project have been provided."[11]

In the Final Environmental Statement for Diked Disposal Island, Hart and Miller Islands, Baltimore County,[10] the problem of actually obtaining rights-of-way for long-distance pipeline was pointed out:

> "A 72 mile long Standard Oil Company gilsonite mineral solids transport line from eastern Utah to Colorado.... Acquisition of lands and routing of this pipeline were relatively easy in the badlands of Utah where most of the land is owned by the

Federal Government. A similar project in the east would require costly acquisition of a right-of-way through the State of Maryland, probably requiring years of negotiation. Particular difficulties would be encountered in installing a pipeline through populated areas."

Typical problems which would be encountered have also been pointed out in discussion of pipeline transportation (although not necessarily referring specifically to dredged material) by Culvern et al.:[12]

> "If the land is near a densely populated area, the cost of an easement may equal or exceed the normal value of the land. Sometimes it is economical to let the route follow a random course which parallels the property ownership lines. Occasionally the cost can be reduced by following existing rights-of-way such as other pipelines, highways, power lines or other established corridors."

Although specifically discussing installation of a large-diameter pipeline for transporting water through urban areas, Buettner[13] points out general factors which should be considered in passing a pipeline through an urban area.

> "...One must consider the installation's impact on traffic and emergency vehicular movement, existing utility relocations, available underground space, pedestrian safety, business enterprises, and the esthetic value of above-ground appurtenances. Future maintenance must receive full consideration and allow easy access to every segment of the conduit....
>
> "The engineers must be thoroughly familiar with, and direct their efforts to strict adherence with, individual community requirements, such as building codes, limits of construction, time and scheduling of operations, storage of pipe and materials, and minimal time periods for utility relocations and service interruptions during conduit installation."

An example of the type of problem which might be experienced in pipeline routing is described by Keshen[14] in a project for pumping hydraulic fill to a housing site in New York City. This necessitated boring beneath a rail freight line, since dynamite could not be used.

> "Crews had to work around the clock as only one man could crawl through the casement pipe to claw at the rock and general fill to complete the bore."

Another routing factor to be examined is the general terrain to be encountered. Reikenis et al.[15] in their DMRP-sponsored study, gave some consideration to this:

> "In the Gulf States Region the feasibility of pipeline transportation is greater than in many other areas of the nation. The low, flat terrain and high potential for beneficial usage in the immediate coastal area create a viable situation for pipeline transportation."
>
> ..."The highly urbanized character of the North Atlantic Region and the change in physiography to a more rugged terrain as one leaves the coastal plain all but preclude this scheme as a feasible method of transporting dredged material."
>
> ..."In the Great Lakes Region...substantial regional use has been suggested for dredged material at locations located some distance inland. Since the nature of the material dredged in this Region eliminates rail or highway transportation, the only practical transportation system is by long distance pipeline. Problems with pipelining in this region include conflicts to be encountered in crossing rail and highway routes and in passing urbanized areas. Transportation problems are compounded in this area by the lack of a major inland waterway system."

Weather Conditions

Weather conditions are another factor which would place limitations to a varying degree on any of the transportation modes considered. In relation to pipeline transport:

> "A common requirement for slurry pipelines that use a water carrier requires burying the pipeline below the frost line to avoid freezing of the slurry. When the pipeline is operating, there is no freezing hazard; however, the pipeline may be shut down and freezing could present a problem.
>
> In temperate areas where freezing is not a problem, above ground construction may be considered; however,

another problem arises. Corrosion rate is a strong function of temperature. For an uninsulated slurry line installed, for example, in a desert, the corrosion rate would rise rapidly. Therefore, it is important to consider the effect of temperature on corrosion rate when providing pipe insulation."[16]

PART V: RAIL HAUL ANALYSIS

General

In evaluating the transport of dredged material over relatively long distances inland for disposal or productive uses, rail haul must be considered a prime transportation mode. Historically, for long-distance inland movements of commodities where rail lines are available, rail haul has been the selected mode of transportation. It is not to say that rail transportation has not had its problems. Typical problems encountered within the rail industry in the past include non-availability of rail cars, poor track maintenance, and poor delivery times.

However, in the last ten years more attention has been directed at these problems and considerable progress has been made toward improving the efficiency of rail transportation. In particular, with the new awareness of the energy limitations and the inherent energy savings advantages of rail transportation, increased emphasis on improving rail transportation capability can be anticipated.

In this regard the transportation of large volumes of coal on a continuing basis from mines to electric utility companies has been growing at a rapid rate. Along with this growth and the potential competition from pipeline slurry transportation, the rail industry has implemented a number of significant improvements in their service to meet this challenge. The development of the unit train concept,

where a dedicated train carrying only one commodity (e.g., coal) from point A to point B on a tightly regulated schedule, has been implemented. This concept has significantly increased efficiency and utilization of rail equipment which, in turn, has permitted substantial rate reductions.

It is anticipated that the movement of dredged material inland by rail will take advantage of the unit train concept because two requisites for a unit train can be met. The first is that the volume of material to be moved at any one time is large enough to fill a complete train (i.e., 5,000-10,000 cubic yards), and, secondly, the transport of the dredged material inland can be expected to occur on a continuing basis. The combination of these two factors resulting in large volumes to be transported annually will permit the economies of scale which are required for a unit train operation. The alternative to the unit train operation is described in the following section.

Technical Analysis

Rail Haul Options

Basically there are two ways to haul freight by rail: single car movement and trainload movement. Single car movement is utilized when the volume to be moved is relatively low, and trainload movement is utilized when volumes are high. Single car movement necessitates single car handling throughout the transportation cycle from car availability to loading to transporting to unloading. Because of the multiple handling steps associated with single car movements, utilization rates are very low and costs are relatively high. On the other hand, the handling requirements for a complete trainload of a given commodity are considerably reduced resulting in lower transportation rates.

For trainload movements of a single commodity, which are most commonly referred to as "unit train" movements, the following three distinctions can be made:

"Trainloads — Some roads operate trainloads of ordinary equipment in a single move at random times on tariffs that reflect a savings to the customer. In many cases, railroads save costs by handling a large tonnage in one block, which moves relatively efficiently by eliminating terminal and hard handling, paper work and car weighing, and by fast turnaround of equipment. Export grain trains, scheduled to coordinate with ship arrivals, are examples of trainload service.

Shuttle Trains — Railroads handling large volumes of coal, grain and ore have a unit train service in which dedicated cars operate between large originating and destination areas. These trains commonly are scheduled well in advance so motive power also can be assigned on a regular basis. Shuttle trains consisting of dedicated equipment, with both locomotives and cars moving continuously between one origin and one destination, are the most advanced application of the unit train concept.

These trains avoid classification yards and are refueled at one or more intermediate terminals. Cars frequently load while in motion and some unload in motion, minimizing terminal time. Other cars, equipped with a rotary coupler at one end, unload in rotary car dumpers while remaining coupled to the remainder of the train. Most unit trains use ordinary railroad equipment, but with modifications such as rotary couplers or rapid-discharge doors and strengthened components. Equipment utilization is high and operating costs are proportionately lower.

Integral Trains — The ultimate application of the unit train concept is in specially designed trains, articulated as one unit with built-in motive power, operating between one origin and one destination in continuous turnaround service, with minimum detention time at either end."[17]

In general, for a given annual requirement to move from 500,000 to 5 million cubic yards of dredged material a year inland by rail, the most representative above definition is the shuttle train. The trainload definition being rejected because of the randomness of the movement and the resultant higher cost, and the integral

train being rejected because of the need for a specially designed train and the potential for higher costs associated with acquisition of specialized equipment. Hereafter in this report the term unit train will be utilized synonymously with the shuttle train definition above.

Generalized Rail Transport System

The minimum annual volume movement required to support a unit train operation is about 500,000 cubic yards per year on a continuing basis from point A to point B, where point A would represent an existing disposal area, and point B would represent a distant inland disposal area. Conceptually, the distance variation from point A to B could vary from 5 to 1500 miles; however, for practical purposes, the rail haul distance has been limited in this study to between 50 and 500 miles in length. For distances under 50 miles, the high fixed cost of loading and unloading rail cars becomes very significant, and dollars per ton-mile rates rise rapidly. Additionally, only fragmentary data are available for unit train operations under 50 miles, and most of these data represent private mining operations. For distances in excess of 500 miles, good cost data is available; however, the extended cost (i.e., \$/cu yd/mile x miles x cu yd) of hauling dredged material in excess of 500 miles would be very high, resulting in an impractical disposal or productive use alternative.*

In order to establish the generalized specification for a unit train to haul dredged material, the nature of the commodity must first be identified. Dredged material coming from an existing disposal site could vary in water content anywhere from a slurry state to a completely dry state. As described earlier, there are two forms of dredged material which are being considered in this

* References 18, 29, 33, and 34 provide data points for rail movements in excess of 500 miles.

study: a slurry state and a relatively dry state. With regard to rail haul movement, only dredged material in a dry state is being considered because greater solid content can be transported in a dry state than in a slurry state. Although rail movement of a slurry mixture is feasible, the costs associated with this alternative will be considerably higher than will be experienced with the movement of dredged material in a dry state.

Sand, as well as a number of other construction aggregate materials, is commonly moved by rail haul. In particular, for the transportation of sand or other type construction aggregate materials, a unit train would be formed with 100 net ton capacity, open-top rail cars which would have a volume of 2,100 cubic feet (77.8 cubic yards) per car. Since dredged material in a relatively dry state has characteristics generally similar to construction type materials, the same capacity rail car would be applicable.

The trend today in purchasing new rail cars for bulk hauling is toward the 100 net ton car. Older bulk hauling cars were in the 70 net ton range; however, most high volume unit trains are comprised of 100 net ton cars. The movement toward even larger capacity rail cars has been slowed somewhat by the unsuitability of the track to handle high traffic volumes with heavier loads.

The final factor to consider in the selection of rail cars for a unit train is the train unloading procedure. As described in the definition of a unit train, a prerequisite to an efficient operation is rapid loading and unloading of the train. In most instances unit trains are scheduled for a three- to four-hour loading and unloading time. In nearly every instance, strict cost penalties are incurred if either loading or unloading exceeds a 24-hour time period. Because of this requirement, efficient unloading methods must be utilized. One of two methods are most commonly utilized for unloading unit trains. The first is the bottom dump method where hopper doors at

the bottom of a hopper car are opened allowing the commodity to free fall out. In this instance the rail cars will bottom dump into an excavated area or will bottom dump from an elevated track. The second unloading method involves the use of a rotary car dumper which actually turns the car upside down and allows the commodity to free fall into a bin below. Both methods are commonly used for unloading unit trains and, in some cases, there are variations on each method to further improve the efficiency of the unloading operation.

With regard to the bottom dump cars, some cars require that the hopper doors be manually opened and closed while others may be hydraulically operated. The angle of the hopper door will also vary from one type of car to another. In some cases shaker units are required to facilitate the unloading of the commodity. Finally, a potential drawback in the use of hopper cars is that for some very fine-grain commodities the material may leak out of the seams of the hopper doors during transit. This potential problem was discussed with railroad company representatives to determine the seriousness of this for dredged material, and in each instance no concern was expressed by these representatives.

When the rotary dump method is used, either hopper or gondola type cars may be utilized. Rotary dumpers are designed to dump one or two cars at a time. In some cases swivel couplings are utilized on the cars to permit dumping without disconnecting rail cars. In general, the rotary dump method is more expensive because the rotary dumper equipment is very expensive (in the order of one million dollars per unit); however, the rotary dump method provides for better discharge of materials with a higher moisture content.

For purposes of this study, either method could be selected for use, and since the bottom dump method is generally the more economical of the two, this method has been selected for usage in cost derivations. In summary, the generalized unit train configuration postulated for

transporting dredged material inland will utilize 77.8-cubic yard capacity, open-top hopper cars. The number of trainloads required will be dependent upon the volume of material to be transported per year. Table 5-1 below presents probable unit train schedules for varying annual volume movements of dredged material. For each specific application, train configurations may vary in the number of cars

Table 5-1

Train Schedules for Different Annual Volumes

Annual volumes (million cu yd)	.5	1	3	5
Daily volumes (cu yd)*	10,000	10,000	10,000	10,000
Train schedule	1 train every day	1 train every day	1 train every day	2 trains every day
No. cars/train	129	129	129	129
% utilization/yr	17.9	35.7	107	89.3

*Based upon 280 operating days per year

utilized and the frequency by which they are run. However, given that a unit train application can be justified by volumes, dollars per ton-mile rates are not very sensitive to variations in annual volumes between 500,000 and 5 million cubic yards, or in the composition of the trainload.[18] This point will be discussed further in the cost analysis subsection.

Loading and Unloading Facilities

As discussed previously, in order to make the unit train concept work and receive the benefits of reduced rates on large volume bulk movement, rapid loading and unloading facilities are essential. In this regard any number of variations on rapid loading and unloading methods can be utilized; however, for the most part one or two common

methods prevail. Figure 5-1 presents a simplified drawing of a typical loading operation. In this operation one or more backhoe diggers (e.g., Caterpillar excavators #245-type) are utilized to excavate the dredged material. This equipment with a 14 1/2-foot stick has a ground level reach of 46 feet and digging depth of 32 feet with a rated production capacity of 6.5 cubic yards a minute.[19] Other equipment, such as big-wheeled front end loaders and bucket wheel excavators, could be utilized in lieu of the above backhoe digger; however, it is believed that the reach and capacity of the backhoe equipment is well suited for the excavation of dredged material from an existing disposal area. Where foundation conditions require, timber or matting pads will be used to support the backhoe diggers.

Utilizing one backhoe digger to excavate the existing disposal area on a 24-hour basis, approximately 9000 cubic yards of material can be excavated per day, and, on a 280 days per year basis, approximately 2.5 million cubic yards of material can be excavated annually. The addition of a second unit doubles this production or permits a reduced work day based upon production quantitites desired. It is believed for practical purposes that the use of two units would be most desirable because the second unit provides a backup capability should one unit fail, while at the same time reducing the daily operational cycle when both units are operating.

The backhoe digger places the dredged material onto a portable belt conveyor which in turn feeds a fixed belt conveyor to one of two 15,000-cubic yard capacity open stockpiles. The portable belt conveyor is moved as required to maintain the initial link between the backhoe diggers and the fixed conveyor installation. The capacity of the portable belt conveyor will be in the order of 1,000 cubic yards per hour. Two small overhead portable feeder bins are loaded by the backhoes and provide for controlled loading of the portable belt conveyor. The size of the portable belt conveyor is a 40-inch width belt.

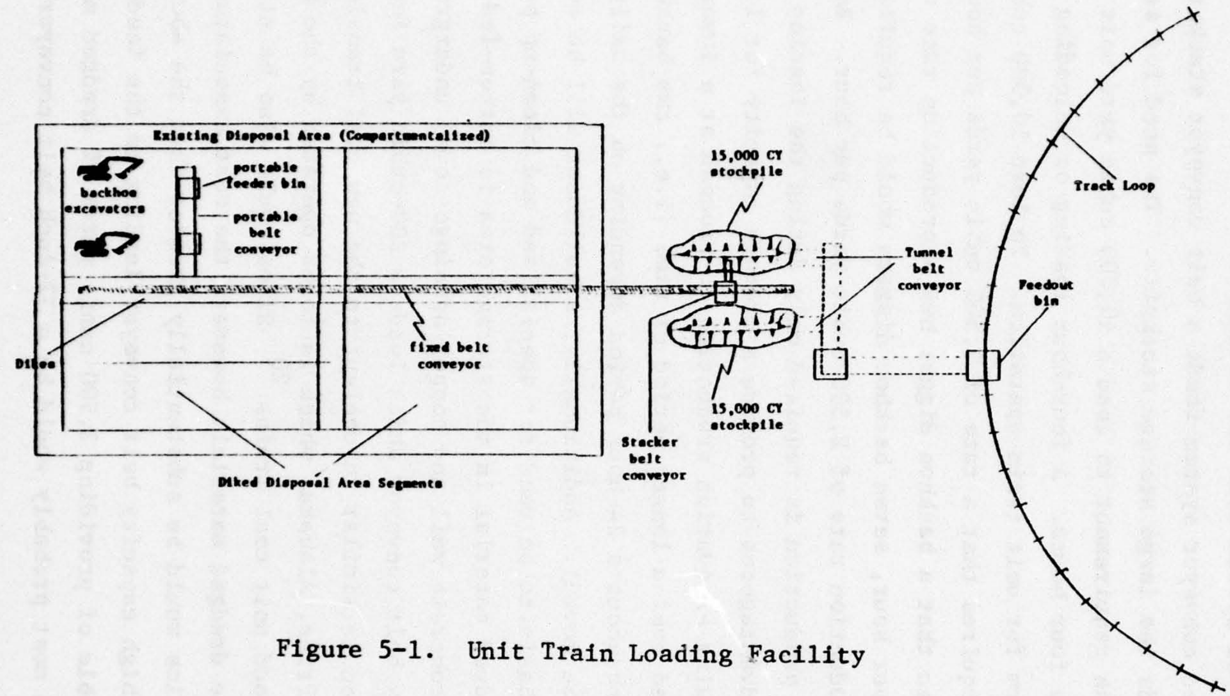

Figure 5-1. Unit Train Loading Facility

Similarly, the fixed belt conveyor has the same capacity and width. The fixed conveyor belt system should be covered to shield the belt and the conveyor system from the weather.

The fixed conveyor system feeds a belt conveyor stacker which, in turn, loads the large storage stockpile. The need for storage is based upon the requirement to load a 10,000 cubic yard unit train in approximately four hours. A four-hour loading or unloading time is about the norm for unit train operation. To load 10,000 cubic yards in four hours requires that a rate of 2,500 cubic yards per hour be established. Given that a backhoe digger has a production rate of 390 cubic yards per hour, seven backhoe diggers would be required to achieve a production rate of 2,500 cubic yards per hour. Because this rate of production is required only during the loading of a train, it appears advantageous to provide a storage capacity for loading, thereby allowing excavation production to proceed at a lower hourly rate stretched over a longer period of time (i.e., two backhoe diggers operating throughout a 24-hour period depending on the daily volume of material to be moved). Additionally, a bulldozer will be required on a part-time basis to be used for specialized and clean-up purposes.

The dredged material in the storage area is bottom-fed through a series of concrete well and hopper openings to an underground, high capacity belt conveyor which loads a 200-cubic yard feedout bin. This operation is similar in concept to the new coal transloading facility at Pride, Alabama, which is to be operated by the Southern Company to load unit coal trains.[20] Silos could also be utilized to stockpile the dredged material; however, the cost associated with utilizing silos would be substantially greater than the above methodology. The high capacity belt conveyor leading to the feedout bin must be capable of providing 2,500 cubic yards of dredged material per hour and most probably would be a 72-inch belt conveyor.

The rail line is a large loop track about 1.5 miles in length. The loading procedures are such that the train maintains a slow continuous movement (i.e., 3 to 4 miles per hour) under the feedout bin which loads each car as it passes under the feedout bin. In this manner the train is not required to stop during the entire loading process. The procedure is common to all unit train operations.

Figures 5-2 and 5-3 present a simplified diagram of the unloading process. As described in the previous subsection, the selected method for unloading the unit train is a bottom dumping procedure where the train moves on an elevated track in the distant disposal area and bottom dumps through hopper doors to a large area below. Normally, one or two cars are dumped at a time, and the material falls into an area which is outloaded by a belt conveyor to trucks or a stockpile for later placement in the disposal area or for a productive use. The feedout conveyor belt would most probably be a 40-inch width belt with a capacity of about 1000 cubic yards per hour.

Related Applications

Currently, there are over one hundred unit train, bulk hauling applications in operation in the United States. The majority of these applications are associated with hauling coal, but this is not to say that other materials are not hauled by unit trains. Grain, phosphate, construction aggregates, and iron ore are currently being transported in unit trains.

Table 5-2 presents a summary of typical unit train applications. Many other unit train applications can be found in the literature; however, this list provides a representative profile of a typical unit train operation. The number of cars per train varies from about 70 to 140. The car size is usually at the 100-ton car capacity. Trainload sizes tend to be around 10,000 tons and distances range from 50 to 1500 miles. The annual tonnages range from 1 to 8 million tons per year.

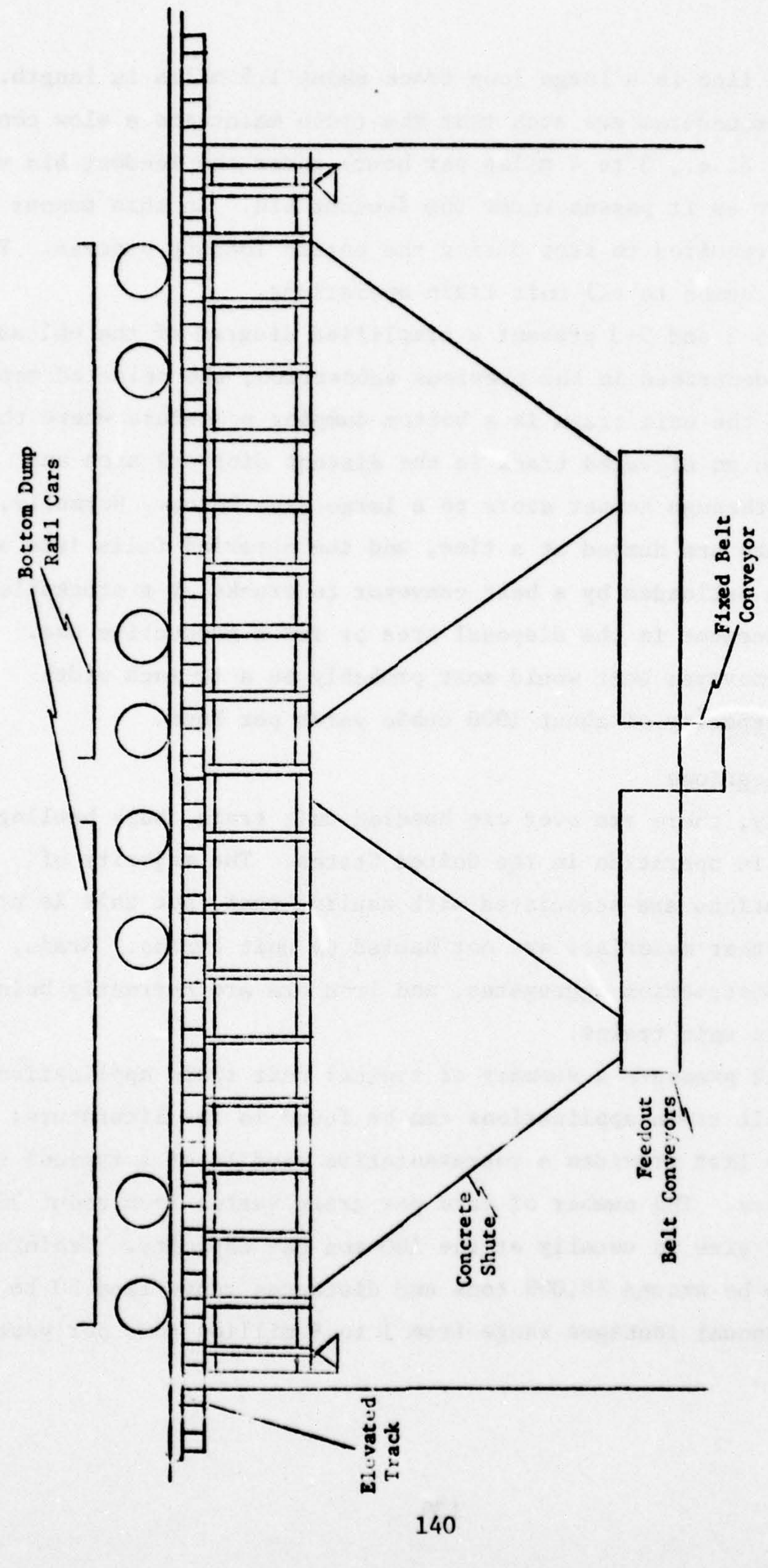

Figure 5-2. Side View, Rail Unloading Facility

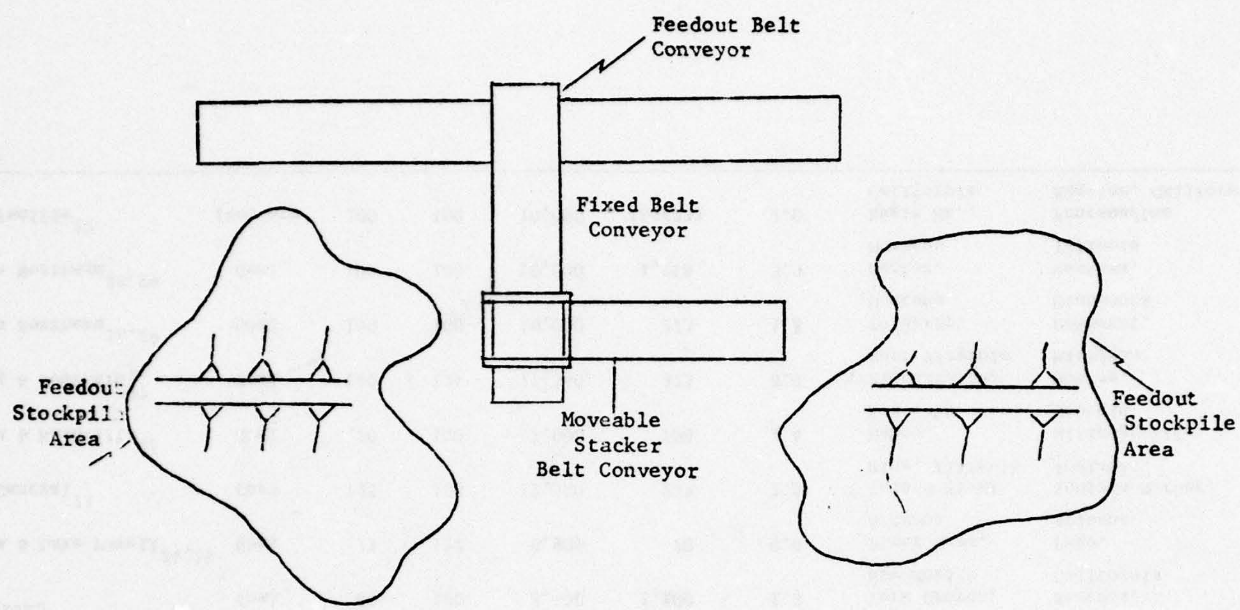

Figure 5-3. Top View, Rail Unloading Facility

Table 5-2

Summary of Typical Unit Train Applications

Rail Line	Commodity	# Cars /Train	Car Size (tons)	Trainload Size (tons)	Distance (miles)	Annual Tonnage (millions)	Origin	Destination
Southern[21]	Coal	85	100	8,500	132	2.6	Parrish, Alabama	Teblowleaf, Alabama
Sante Fe[22,23]	Coal	84	100	8,400	1,100	1.5	York Canyon, New Mexico	Fontana, California
Black Mesa & Lake Powell[24,25]	Coal	73	122	8,906	78	8.0	Black Mesa, Arizona	Page, Arizona
Illinois Central[21]	Coal	125	100	12,500	279	1.5	Inland Steel Mine, Illinois	Indiana Harbor, Indiana
Louisville & Nashville[26]	Coal	70	100	7,000	700	1.4	Wahoo, Kentucky	Milledgeville, Georgia
Waynesburg & Southern[27]	Coal	140	124	17,360	375	8.0	Blacksville, West Virginia	Monroe, Michigan
Burlington Northern[28,29]	Coal	100	100	10,000	773	1.8	Colstrip, Montana	Cohasset, Minnesota
Burlington Northern[28,29]	Coal	100	100	10,000	1,168	3.3	Decker, Montana	Haviana, Illinois
Southern Pacific[22]	Iron ore	100	100	10,000	164/231	7.0	Eagle Mt., California	Fontana/Los Angeles, California

Cost Analysis

Rail Pricing

The establishment of freight rates by the railroads is complex and not clearly defined. The following presents an overview for the establishment of freight rates:

> "All railroads as common carriers, are required by law to publish rates on commodities they carry and subject to procedures laid down by the Interstate Commerce Commission.
>
> All rail rates fall into two general categories, i.e., class rates and commodity rates. Class rates generally apply to shipments in small volume and on an irregular basis, and generally would not be applicable to industrial minerals shippers. Commodity rates apply to those movements of a specific commodity that usually move on a regular basis between established points in sufficient volume and with competitive factors which justify a rate lower than a class rate.
>
> Many factors must be considered in proposing and establishing a freight rate. The more important ones are:
>
> 1. Investment in equipment
> 2. Established rate structure
> 3. Competition
>
> Operating costs for moving freight between points on a railroad system vary considerably. They are influenced by such things as terrain, distance, car switching and volume. In any scheduled move the cost is greater if there is an uphill haul or if there are numerous switches of cars from one train to another. However, the cost is not directly proportional to the distance moved, nor does it increase in direct proportion to the volume handled per train. These are examples of items that must be considered in determining operating costs to handle a given ton of freight. Also critical to the establishment of a rate is the obvious impact of investment in equipment.
>
> Established rate structures must be considered in any proposed rate. By this we mean that competitive rates may already exist on movements of a given commodity from the same general geographic area. Such rates may be moving considerable traffic by the railroad considering a proposed

rate, or by competing roads. Arbitrary changes in rates could place an existing shipper in an unfavorable position and also could reduce the carrier's revenue on existing traffic.

"Bearing in mind that there are ways whereby freight costs can be reduced such as increasing the utilization of equipment, loading of cars to full capacity and improving car turnaround, the shipper should consult his local carrier for help. Open hopper cars represent a lower investment than covered hopper cars and frequently rates are lower on commodities that can be moved in open hopper cars, this should be considered when a car type is specified. A further point that bears consideration is the advantage of a one line haul over a two or more line haul. Switching a car from one line to another during transit increases the handling costs, and thus the rate. Naturally, it is not always possible to dictate that a market for a commodity be located on the same railroad that originated it. But it could apply in the selection of a plant site when the major market is known prior to the site location."[30]

For unit train operations, bulk rates are established separately through negotiation between the shipper and the carrier. In general, no relationship exists between conventional train freight rates and unit train rates. One railroad provided the following considerations required to arrive at a unit train rate:

> Each of our trainload movements is individually priced because of the many variables involved; that is, terrain, crews, cycles, number of cars, types and costs of equipment, characteristics of material transported, and equipment maintenance and ownership.*

Another factor not mentioned above is the influence of competition on the establishment of unit train rates. This effect was observed by Consolidated Coal Company in Cadiz, Ohio. In 1957, Consolidated Coal started operation of a 108-mile coal slurry pipeline because of the high costs of rail haul. However, within a couple of years the Baltimore and Ohio, the Pennsylvania, and Southern railroads reduced their rates substantially to meet the challenge of pipeline

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* Proprietary correspondence.

slurry competition.[31] The unit train concept was essentially developed to meet the competitive threat of pipeline transportation. A further indication of the influence of competition is provided below:

> "Many factors are considered in constructing railroad rates. Rates in most regions show a low correlation to distance and variable costs, probably for several reasons:
>
> 1. Costs were unknown or never studied.
> 2. Competitive origins and modes set the rate levels.
> 3. In the absence of competition, carriers charge what the traffic will bear."[32]

The potential wide variation in rail freight rates will be apparent when the freight rate cost versus distance curve is observed in a later section of this report.

Cost Derivation Assumptions

Rail transportation costs can be divided into three basic areas: loading costs, transportation rates, and unloading costs. Loading costs vary depending on the nature of the material to be loaded and the form in which it is available. For purposes of this study, the dredged material to be hauled by rail is dry and in an unexcavated state. The weight of a cubic foot of dredged material is assumed to be about 100 pounds. The loading process, as depicted in Figure 5-1, involves the excavation, handling, storing, and loading of unit trains. The excavation, handling, and storing of the material are assumed to be performed on a 24-hour, six days per week basis for 280 working days in a year. Operations are assumed to be on a contract basis. The actual loading of a unit train is accomplished in about four hours. Equipment utilization and loading operations may vary from application to application; however, in order to arrive at a generalized cost estimate for comparative purposes, it is believed that the procedure depicted in Figure 5-1 provides a representative profile of a typical loading operation.

Rail transportation rates vary depending on the use of shipper- or carrier-owned equipment. In general, shipper-owned equipment (i.e., cars and engines) yields a lower freight rate than carrier-owned equipment; however, the assumption made in this study is that all rail equipment is carrier owned. This assumption is made because it is believed that the Corps does not want to get involved in the ownership of rail cars and/or engines. It is further assumed that a given rail haul application will involve only a single rail line and that track is in place between the existing disposal area and the distant disposal area. It should be noted that the installation of a 1.5-mile track loop at the loading and unloading areas is provided for as a separate cost element under the loading and unloading facilities subdivision. No upgrading of the existing track is anticipated for the movement of dredged material.

The unloading facility, as depicted in Figures 5-2 and 5-3, includes the placement of the dredged material at a location near the rail siding in the distant disposal area. No provision has been included to disperse the material within the distant disposal area or other potential processing applications.

Cost Derivation for Rail Car Loading Operations

Table 5-3 presents the derivation of the estimated yearly costs associated with the fixed investment of a typical rail car loading facility. Table 5-4 presents the derivation of the estimated yearly variable costs associated with the rail car loading operations. Table 5-5 provides a summary of the combined fixed and variable costs associated with the rail car loading operation, and further provides for the allocation of these data on a cents per cubic yard per mile basis for varying transportation distances and varying annual quantities of material being transported.

Table 5-3

Fixed Cost Derivation - Rail Loading Facility

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc. Rate (%)	Annual Maintenance, Repair, Insurance, Security, Misc. Charge (% x Basic Cost)	Total Annual Cost
2 portable feeder bins for belt conveyor (5 cu yd ea. @ $10,000 ea.)	$20,000	$5,000	$25,000	20	$2,360	32	$6,400	$8,760
1 portable belt conveyor (40" belt, 1000 cu yd/hr, 1250 ft length @ $400/ft)	500,000	125,000	625,000	20	58,994	27	135,000	193,994
1 fixed belt conveyor (40" belt, 1000 cu yd/hr, 3500 ft length @ $400/ft)	1,400,000	350,000	1,750,000	20	165,183	18	252,000	417,183
1 belt stacker on tracks (40" belt, 1000 cu yd/hr, 60 ft boom @ $500,000 ea.)	500,000	125,000	625,000	20	58,994	12	60,000	118,994
1 rail track for stacker (500 ft length @ $40/ft)	20,000	5,000	25,000	20	2,360	10	2,000	4,360
2 concrete tunnel networks (500 ft length, 12 openings and feeder bins, 8" thick concrete, @ $300/ft)	300,000	75,000	375,000	20	35,396	5	15,000	50,396
2 belt conveyor-tunnels (72" belt, 3000 cu yd/hr, 800 ft length, @ $600/ft)	960,000	240,000	1,200,000	20	113,268	19	182,400	295,668
1 feedout bin (200 cu yd, with structure, swing chute, feed-out controls @ $300,000 ea.)	300,000	75,000	375,000	20	35,396	32	96,000	131,396
1 rail track loop (1.5 mile length with switching @ $250,000/mi)	375,000	93,750	468,750	20	44,245	10	37,500	81,745
								$1,302,496
							Estimate	$1,300,000

Table 5-4

Variable Cost Derivation - Rail Loading Operation

Item	Description	Annual Cost
Disposal Area Excavation	2 backhoe excavators, 13 hrs/day, 280 days/yr @ $55/hr ea	$400,400
	4 backhoe operators, 8 hrs/day, 280 days/yr @ $12/hr*	107,520
Facility Operations	2 shifts @ 5 men/shift, 280 days/yr @ $9/hr*	201,600
	1 bulldozer, 8 hrs/day, 280 days/yr @ $24/hr	53,760
	1 bulldozer operator, 8 hrs/day, 280 days/yr @ $12/hr*	26,880
Electric Power	400 hp @ 13 hrs/day, 280 days/yr @ $.0157/hp hr	22,859
	600 hp @ 4 hrs/day, 280 days/yr @ $.0157/hp hr	10,550
		$823,569

* Includes contractor overhead and fee @ 50 percent.

Table 5-5

Summary of Rail Loading Costs

Item	Annual Volume (Cubic Yards per Year)			
	500,000*	1,000,000	3,000,000	5,000,000
Utilization percent	17.9	35.7	107.0	89.3
Fixed yearly cost ($000)	1,300	1,300	1,300	1,300
Variable yearly cost ($000)	147	294	882	1,472
Total yearly cost ($000)	1,447	1,594	2,182	2,772
Dollars per cubic yard	2.89	1.59	0.73	0.55
Allocated cost per mile (cents per cubic yard per mile)				
@ 50 miles	5.78	3.18	1.46	1.10
@ 100 miles	2.89	1.59	.73	.55
@ 300 miles	.96	.53	.24	.18
@ 500 miles	.58	.32	.15	.11

* Although at the low annual volume level the fixed costs associated with a loading facility become controlling cost elements, unit train operations remain substantially more economical than single car operations.

Rail Transportation Rate Derivations

Figure 5-4 presents curves depicting the estimated rail haul charges associated with transporting dredged material from 50 to 700 miles. These curves reflect only transportation costs and do not reflect loading or unloading costs. As can be seen, three curves are shown: the upper curve represents a high estimated rate limit, the lowest curve represents a low estimated rate limit, and the middle curve represents the most likely rail haul rate.

Because each rate is individually negotiated and different applications will involve unique requirements, it is impossible to establish a single generalized rail transportation rate. The data points in Figure 5-4 were obtained from differing sources, and in some cases reflect current estimates* (denoted by circled dots) from several different railroad companies, while in other cases they represent actual or averages of actual rates charges (denoted by Xs).** It should be noted that original data points were translated into cents per cubic yard per mile from cents per ton per mile based on 100 pounds per cubic foot.

Cost Derivation for Rail Car Unloading Operations

Table 5-6 provides the derivation of the estimated yearly costs associated with the fixed investment of a typical rail car unloading facility. Table 5-7 presents the derivation of the estimated yearly variable costs associated with the rail car unloading operations. Table 5-8 provides a summary of the combined fixed and variable costs associated with the unloading operation. Summarized costs were derived on a cents per cubic yard per mile basis for varying distances and annual volumes.

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* Railroad estimates represent proprietary data.

** Refer to references 18, 29, 33, and 34 to obtain specific data points.

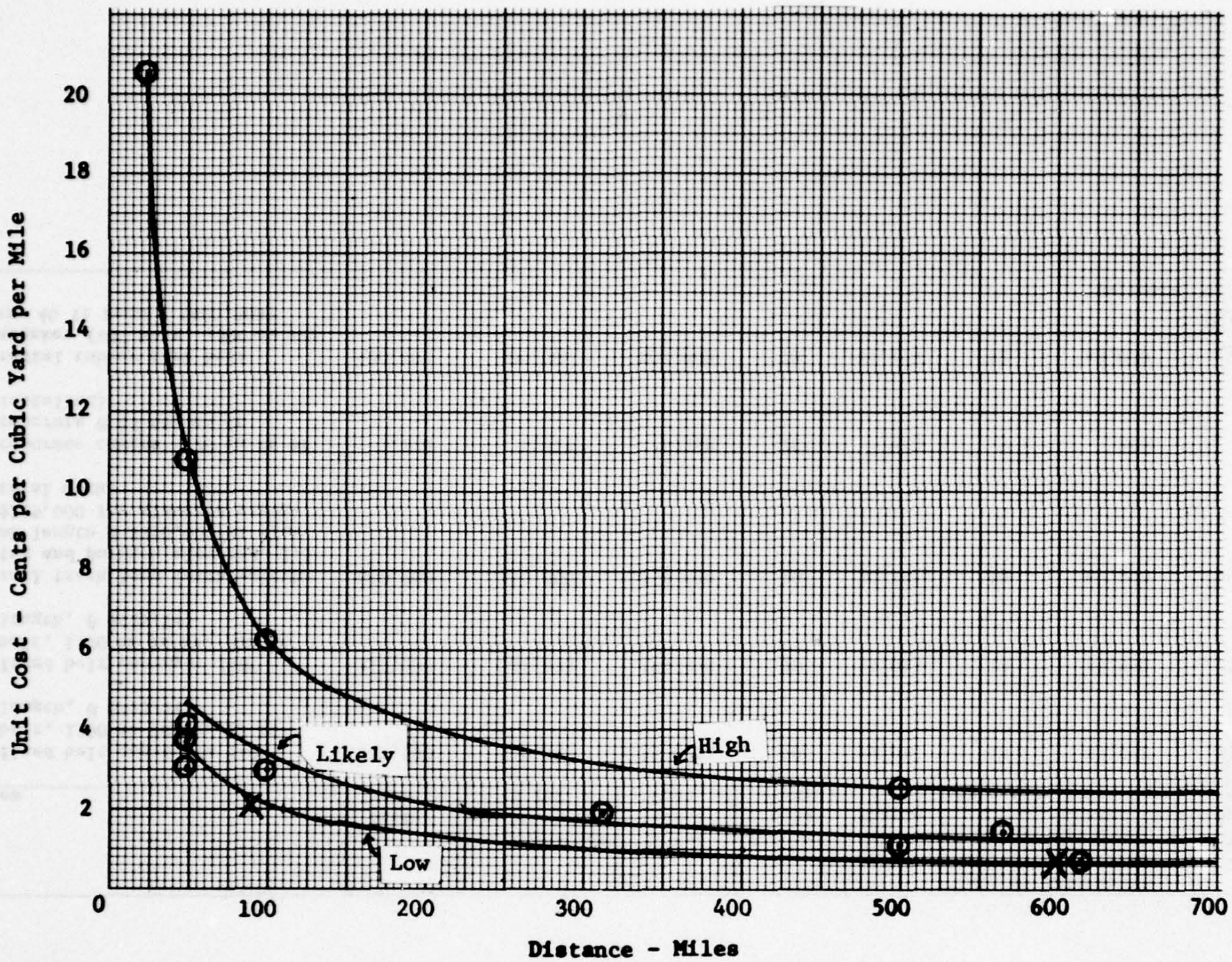

Figure 5-4. Rail Transportation Rates vs Distance
(Exclusive of Loading/Unloading Cost)

Table 5-6

Fixed Cost Derivation - Rail Unloading Facility

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc.		Total Annual Cost
						Rate (%)	Charge (% x Basic Cost)	
2 fixed belt conveyors (40" belt, 1300 cu yd/hr, 50 ft length, @ $425/ft)	$42,500	$10,625	$53,125	20	$5,014	18	$7,650	$12,664
1 fixed belt conveyor (40" belt, 1300 cu yd/hr, 300 ft length, @ $425/ft)	127,500	31,875	159,375	20	15,043	18	22,950	37,993
1 rail track loop (with switching and portion elevated, 1.5 mi length @ $250,000/mi plus $225,000 for elevated structural work)	600,000	150,000	750,000	20	70,792	10	60,000	130,792
2 concrete chutes (720 cu ft of concrete @ $3.661 cu ft installed)	5,270	1,318	6,588	20	623	5	264	887
1 radial rubber tire belt stacker (40" belt, 1300 cu yd/hr, 40 ft boom @ $400,000)	400,000	100,000	500,000	20	47,195	12	48,000	95,195
								$277,531
							Estimate	$277,000

Table 5-7

Variable Cost Derivation - Rail Unloading Operation

Item	Description	Annual Cost
Operations	1 shift, 4 men, 280 days/year @ $9/hr*	$80,640
	1 track-type loader, 1 shift, 280 days/yr @ $11.23/hr	25,155
	1 loader operator, 1 shift, 280 days/yr @ $12/hr*	26,880
Power	250 hp, 8 hr/day, 280 days/yr @ $.0157/hp hour	8,792
		$141,467

*Includes contractor overhead and fee @ 50%.

Table 5-8

Summary of Rail Unloading Costs

	Annual Volumes (Cubic Yards per Year)			
	500,000	1,000,000	3,000,000	5,000,000
Utilization percent	17.9	35.7	107.0	89.3
Fixed yearly cost ($000)	277	277	277	277
Variable yearly cost ($000)	25	50	150	252
Total yearly cost ($000)	302	327	427	529
Dollars per cubic yard	0.60	0.33	0.14	0.11
Allocated cost per mile (cents per cubic yard per mile)				
@ 50 miles	1.20	.66	.28	.22
@ 100 miles	.60	.33	.14	.11
@ 300 miles	.20	.11	.047	.037
@ 500 miles	.12	.066	.028	.022

Total Rail Haul Costs

Total rail haul costs* for the movement of dredged material long distances inland are provided in Table 5-9, Figure 5-5, and Figure 5-6. It can been seen from Figure 5-5 that unit cost rates decrease both with distance traveled and with larger annual volumes of material being transported. For distance traveled, the loading, transportation, and unloading unit costs all decline, resulting in substantially reduced unit cost rates at the 500-mile point. At the 500-mile distance, the major cost element is the rail transportation rate which itself is beginning to approach an asymptotic value (refer to Figure 5-4). This asymptotic effect is also observed when examining the impact of different annual volumes. As before, at larger volumes the primary unit cost element is the rail transport cost, which is effectively constant for volumes in excess of 500,000 cubic yards per year. Additionally, it can be observed that for the shorter distances and lower volumes, the composite unit costs rise substantially because the unit costs associated with the loading and unloading facilities have more significance. Figure 5-6 provides railroad costs on a dollars per cubic yard basis for varying distances and volume movements.

In summary, Figures 5-5 and 5-6 provide a generalized picture of the total cost rates that can be expected in moving dredged material long distances inland by rail haul. Variations in these rates can be expected between geographical locations and between specific transportation applications; however, for comparing costs between different transportation modes, it is believed that these rates are representative of rail haul costs for transporting dredged material inland.

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* Based upon the estimated most likely transportation rate case.

Table 5-9

Total Rail Haul Cost Summary

Cost (Cents per Cubic Yard per Mile)	Annual Volumes (Cubic Yards per Year) 500,000	1,000,000	3,000,000	5,000,000
50-Mile Distance				
Loading	5.78	3.18	1.46	1.10
Transportation	4.60	4.60	4.60	4.60
Unloading	1.20	.66	.28	.22
Total	11.58	8.44	6.34	5.92
(Dollars/cubic yard)	($5.79)	($4.22)	($3.17)	($2.96)
100-Mile Distance				
Loading	2.89	1.59	.73	.55
Transportation	3.00	3.00	3.00	3.00
Unloading	.60	.33	.14	.11
Total	6.49	4.92	3.87	3.66
(Dollars/cubic yard)	($6.49)	($4.92)	($3.87)	($3.66)
300-Mile Distance				
Loading	.96	.53	.24	.18
Transportation	1.80	1.80	1.80	1.80
Unloading	.20	.11	.05	.04
Total	2.96	2.44	2.09	2.02
(Dollars/cubic yard)	($8.88)	($7.32)	($6.27)	($6.06)
500-Mile Distance				
Loading	.58	.32	.15	.11
Transportation	1.40	1.40	1.40	1.40
Unloading	.12	.07	.03	.02
Total	2.10	1.79	1.58	1.53
(Dollars/cubic yard)	($10.50)	($8.95)	($7.90)	($7.65)

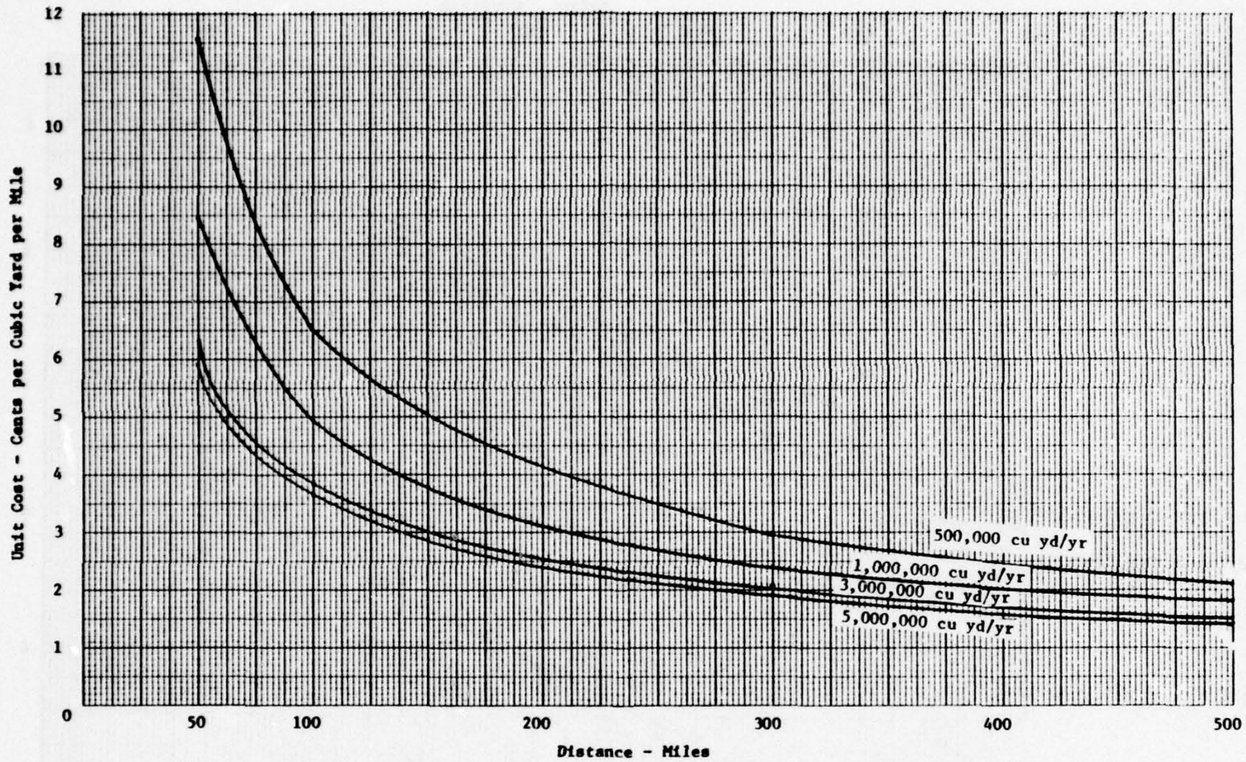

Figure 5-5. Total Rail Haul Unit Costs for Varying Annual Quantities

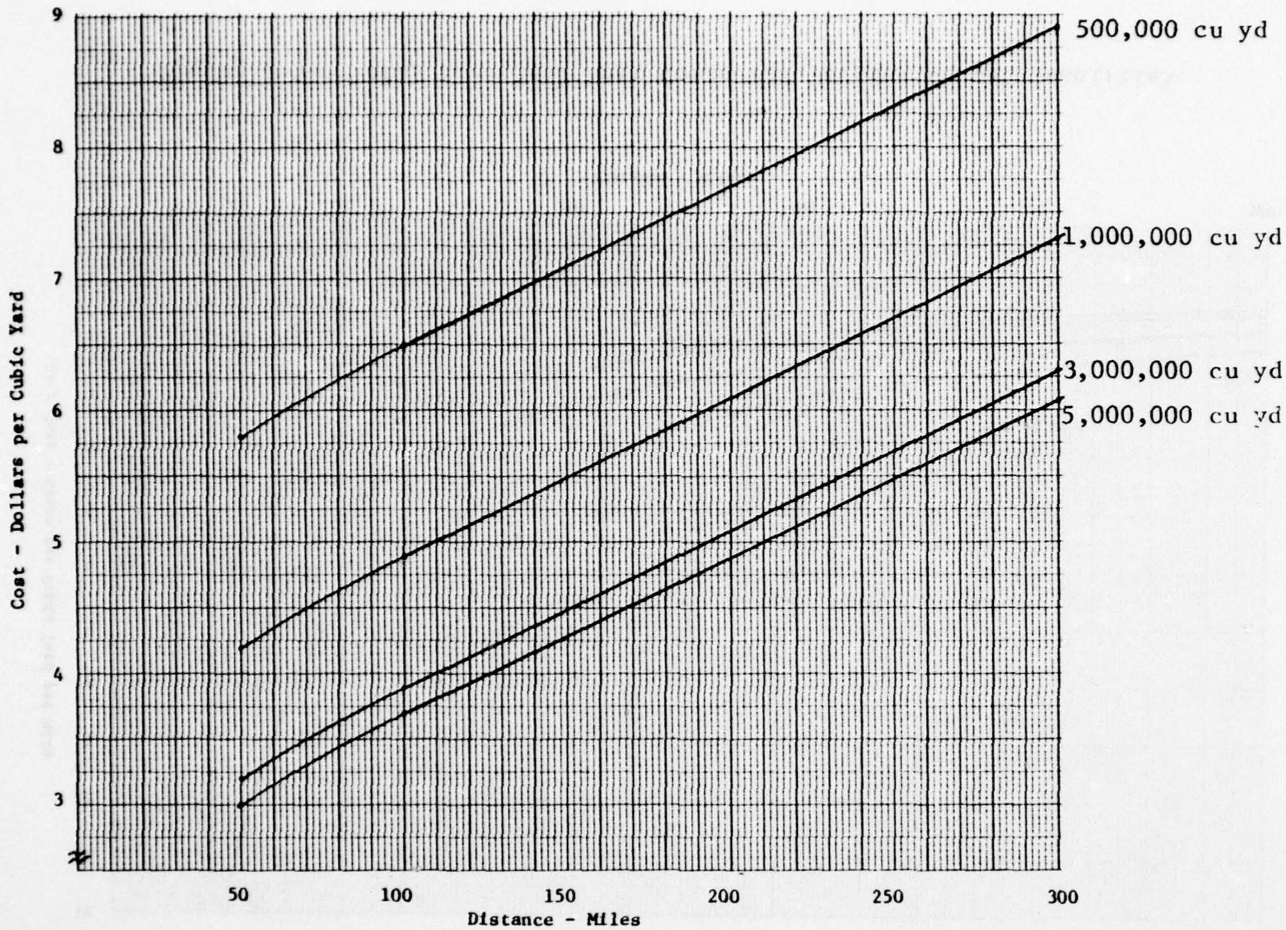

Figure 5-6. Total Rail Costs (Dollars per Cubic Yard) for Varying Annual Quantities

Additional Rail Haul Considerations

If rail haul of dredged material is selected as a viable transportation mode based on economic reasons, some additional considerations associated with rail haul of dredged material must also be examined.

Moisture Content

The material being moved must be dry enough to free fall out of bottom dump rail cars or out of feeder bins. If the material has a moisture content which will not permit the material to free fall, serious problems in material handling will be encountered.

Train Length

Unit train lengths can sometimes be a problem where local laws place limits on the maximum amount of time that a road intersection can be tied up due to a train passing through.

Environmental Regulations

In considering the use of a rail transport system for moving dredged material inland, regulations established by recent environmental legislation would have to be met including the Clean Air Act of 1970, concerning the prevention and control of air pollution and the Noise Control Act of 1972, concerning noise emission standards. However, while the Noise Control Act provides for Federal regulation of railroad noise, the Clean Air Act does not preempt state and local regulation, an important factor for interstate rail transportation.

In this regard, a problem may be encountered with the material blowing from the open top hopper cars. If this occurs, the hopper cars will have to be covered in some manner. Various covering techniques are available and the rail carriers should be questioned on which technique they prefer.

Residue

The Craney Island Disposal Study[8] considered the possibility of using unit trains returning empty to West Virginia and Western Virginia. However, this plan would require washing of the cars after unloading the dredged material in order to avoid the possible contamination of coal being transported to the Hampton Roads area. An additional problem with this plan would be that of disposal of the residue after washing the cars.

Weather Conditions

Weather conditions could adversely affect the transportation of dredged material by rail haul. Excessive rainfall or freezing temperatures could significantly affect the handling characteristics of the material. The seriousness of this potential problem is unknown at this time but it should be investigated prior to implementation of rail transportation applications.

The purpose of the identification of the above considerations is not to cast doubts on the viability of rail haul movement of dredged material but rather to insure that unforeseen problems do not arise subsequent to the possible selection of rail haul as the desired mode for the transportation of dredged material inland.

PART VI: BARGE MOVEMENT ANALYSIS

General

Barge movement has been in the past and continues to be an efficient means of transportation for bulk materials. Due to its relatively low operating costs, the barge industry can compete quite easily for high volume movements of low valued bulk material. Approximately two-thirds of the inland waterways traffic is made up of five bulk commodities: coal, petroleum and petroleum products, agricultural products, iron and steel, and chemicals.[35]

The inland waterways system is a network of over 25,000 miles of navigable waterways. A breakdown of the major geographical areas that are part of the inland waterways network is as follows:

- Mississippi River System - 36 percent
- Gulf Intracoastal Waterway and Gulf Coast Waterway - 22 percent
- Atlantic Intracoastal Waterway and Atlantic Coast Waterways - 28 percent
- Pacific Coast - 14 percent[36]

Since 1950 barge cargo tonnage has nearly doubled and ton-miles have increased fivefold.[37] Currently the industry has in operation 4100 towboats and 25,410 barges.[37] In 1971, the average length of a barge haul was 413 miles.[37]

The natural advantage that the barge industry has in the movement of bulk commodities long distances is based upon the following factors:

- Inland waterways are maintained by the Army Corps of Engineers at no cost to the industry.
- Relatively low fuel consumption per ton-mile.
- Many major trade areas are located adjacent to the inland waterway system.

These factors lead to relatively low operating costs and substantial demand for their services.

The basic disadvantages of barge movement are:

- Barge movement is limited to the geography of the waterways (which often do not provide a straight path from origin to destination).
- Relatively slow speed for freight transportation.

However, given that a waterway route exists, the drawback of slow transportation speed is not particularly important for the movement of dredged material.

Technical Analysis

Barge Movement Options

The options related to barge movements are relatively limited. In general the larger the barge size, the more economical the operation; however, large sizes are limited based upon lock sizes and draft of the barges. The most popular size of dry cargo barge is the 1500-short ton size which has dimensions of 195 feet long by 35 feet wide with a draft of 9 feet.[36] In most cases barges are moved in groups by a powered vessel (a towboat). Tow sizes will vary anywhere from one to 40 barges depending upon the use to which they are put.

For the movement of dredged material, open-topped dry cargo barges will be utilized. Covered hopper barges and tank barges are available; however, for purposes of this study where the material is in a relatively dry state, open-top hopper barges are expected to be sufficient and more economical. Barge haul of dredged material in a slurry form is possible but as indicated in the rail haul analysis, a greater quantity can be moved if the material is in a dry state.

Self-propelled barges are also available, but their usage is rather limited; for purposes of the study, it is believed desirable to utilize the most readily available and common equipment in inventory.

Tugboats generally have two to four diesel engines driving twin propellers, configured for maneuvering at shallow depths. Most tugboats in use today have from 1000 to 8400 horsepower depending on their desired use.

Generalized Barge Transportation System

For purposes of the transport of dredged material inland, a barging unit of one 1000-horsepower tugboat and two 1500-cubic yard, steel, bottom-dump scows will be utilized. If a given application requires more hauling capacity than can be generated by a single barge unit, additional barging units will be utilized. The definition of the above barging unit is based upon two basic considerations:

- First, it is anticipated that readily available and common equipment will be utilized.
- Secondly, the smaller tow provides for greater flexibility of operations.

In order to determine the number of barging units required for a given application, both the annual volume to be transported and the distance over which the material is to be moved must be analyzed. Additionally, the estimated loading and unloading times will affect the overall cycle time required for the movement and, in turn, will affect the number of barging units required.

Loading and Unloading Facilities

Depending on the characteristics of the disposal area involved (e.g., urban versus rural location), belt conveyors or trucks could be used to bring dredged material to the barge loading dock. Of these modes, trucks are most applicable to the widest range of operating conditions; for this reason, the current generalized analysis assumes that trucks will be used for this purpose.

In cases where the distances between disposal areas and barge loading docks are short and the areas involved are not congested, belt

conveyors could be the more economical transportation mode. A preliminary analysis has revealed, for example, that over a distance of 1.5 miles:

- Trucks are most economical when the annual volume of dredged material is relatively low (e.g., 500,000 cubic yards per year);
- Belt conveyors are most economical when the annual volume of dredged material is relatively high (e.g., 5,000,000 cubic yards per year).

Based on these results, it would be desirable to consider belt conveyors for barge loading in specific instances where their application appears feasible.

As in the case of the rail loading operation and also as shown in Figure 6-1, two backhoe diggers excavate a diked section of the existing disposal area where the dredged material is in a relatively dry state. However, in the case of the barge loading operation, the backhoe diggers load directly into 11.1-cubic yard capacity (15-ton) dump trucks for subsequent truck haul to the barge at the mooring dock. In order to permit truck operations in the disposal area, a 20-foot gravel roadbed is prepared along the dikes to access and egress from the disposal area, and at 40-foot intervals in the disposal section which is being excavated. In effect, a gravel roadbed loop will be prepared for a continuous one way flow of truck traffic into and out of the excavation area. As the backhoe diggers complete excavation of a strip, they will be moved back onto the gravel roadbed area and the truck traffic will fall back to the next gravel roadbed loop for loading.

It should be noted that the methodology to be utilized for excavating an existing disposal area is dependent upon the state of the material in the disposal area. The excavation methodology postulated above is only one of a number of possible schemes and requires that the material in the disposal area be dry enough to support truck traffic over a stabilized roadbed. If this condition does not exist, other methods of excavation would be required.

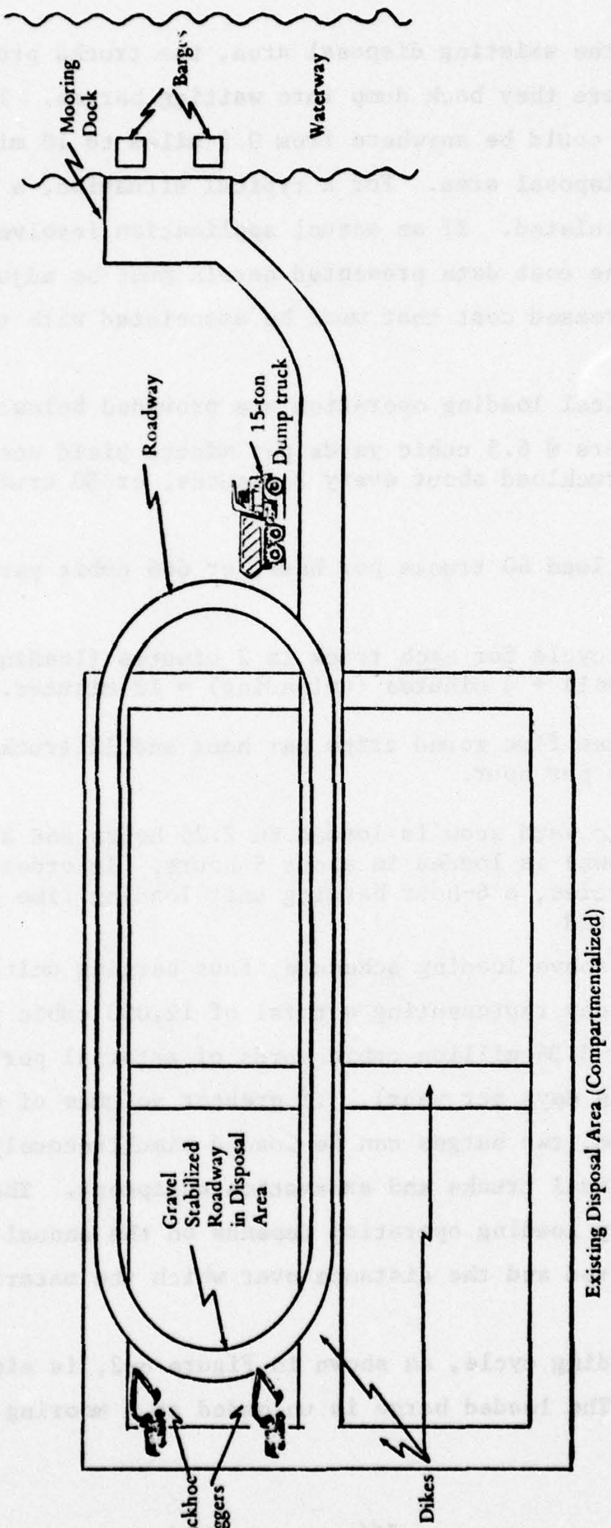

Figure 6-1. Barge Loading Operations

After leaving the existing disposal area, the trucks proceed to the mooring dock where they back dump into waiting barges. The distance of the mooring dock could be anywhere from 0.5 miles to 10 miles away from the existing disposal area. For a typical situation, a distance of 1.5 miles is postulated. If an actual application involves a greater distance, the cost data presented herein must be adjusted to account for the increased cost that must be associated with the increased distance.

Data for a typical loading operation are provided below:

- Backhoe diggers @ 6.5 cubic yards per minute yield one 11.1-cubic yard truckload about every 2 minutes, or 30 truckloads per hour.

- Two backhoes load 60 trucks per hour, or 666 cubic yards per hour.

- A round trip cycle for each truck is 2 minutes (loading) + 6 minutes (travel) + 4 minutes (unloading) = 12 minutes.

- One truck makes five round trips per hour and 12 trucks provide 60 truckloads per hour.

- One 1500-cubic yard scow is loaded in 2.25 hours and a barging unit (two scows) is loaded in about 5 hours. In order to allow for contingencies, a 6-hour barging unit loading time period will be selected.

Based upon the above loading schedule, four barging units can be loaded in a 24-hour day representing a total of 12,000 cubic yards of material per day, or 3.36 million cubic yards of material per year (based on 280 working days per year). If greater volumes of material movement are required, two barges can be loaded simultaneously but this requires additional trucks and excavation equipment. The actual duration of the daily loading operation depends on the annual volume of material to be moved and the distance over which the material must be barged.

The barge unloading cycle, as shown in Figure 6-2, is similar to the loading cycle. The loaded barge is unloaded at a mooring dock

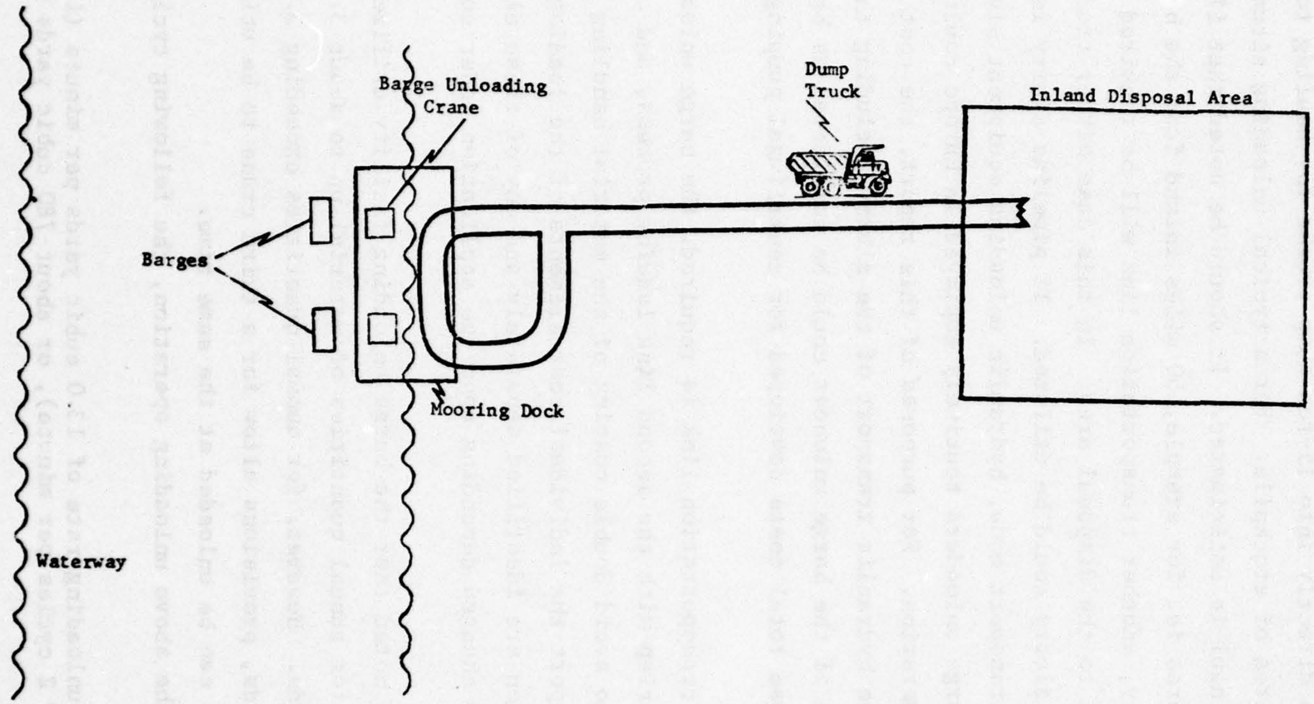

Figure 6-2. Barge Unloading Facility

containing two unloading, clamshell-type cranes with a capacity of about 3.25 cubic yards per cycle each. The crane is utilized to unload the barges directly into 15-ton dump trucks for hauling to the nearby disposal area of stockpile. For a typical unloading situation, a 1.5-mile truck haul is anticipated. It should be noted that if the inland disposal area is, for example, 50 miles inland from the barge unloading facility, another transportation link will be required to move the material to the disposal area. In this case either truck haul or pipeline slurry could be utilized. If pipeline slurry is utilized as the transport mode, hydraulic unloading equipment similar to the typical barge unloaders routinely employed in Europe could be adapted to the operation. For purposes of this report, the cost per cubic yard for the hydraulic transport of the slurry including the cost of operation of the barge unloader could be considered as being comparable to those total costs developed for centrifugal pumping systems.

If a second transportation link is required, the barge unloading process would overlap with the second link loading process, and care should be taken to avoid double costing of the material handling process. In this report the individual cost elements of the loading and unloading operation are identified separately and any of these elements can be removed or changed depending upon the application under consideration.

It should be noted that the barge unloading facility utilizes two unloading cranes for annual quantities of material up to about 3.4 million cubic yards. However, for annual quantities exceeding 3.4 million cubic yards, provisions allow for a third crane to be utilized where three scows can be unloaded at the same time.

Based upon the above unloading operation, the following cycle is anticipated:

- A maximum unloading rate of 13.0 cubic yards per minute (i.e., 2 cranes @ 2 cycles per minute), or about 780 cubic yards per

hour. In order to allow for contingencies, a 666 cubic yard per hour rate (i.e., the same as the loading cycle) will be utilized.

- Two 1500-cubic yard scows are unloaded in a 6-hour period.
- Four barging units can be unloaded over a 24-hour period.
- A round-trip cycle for the trucks from the barge to the disposal area will be 12 minutes, and one truck will make five round trips per hour.
- Twelve trucks are required to satisfy the unloading rate of 666 cubic yards per hour.

Barging Operational Cycle Time

As indicated in the prior section, the barging unit loading and unloading times are estimated to be as follows: loading time ≃ 6 hours and unloading time ≃ 6 hours. The estimated average speed of the barging unit is 6 miles per hour. Therefore, the total cycle time for a single barging unit at varying distances will be as follows:

Miles (point to point)	Time (hours) Loading and unloading	Travel	Total	Days	No. barging units required to load a unit every 6 hours	Annual cu yds moved/yr @ 280 days/yr
36*	12	12	24	1	4	3,360,000
72	12	24	36	1.5	6	3,360,000
108	12	36	48	2	8	3,360,000
324	12	108	120	5	20	3,360,000
468	12	156	168	7	28	3,360,000

On this table the number of barging units needed to achieve a continuous loading and unloading operation is indicated. Given 280 days of operation per year, the annual volume of material movement will be 3,360,000 cubic yards for each distance. Therefore, in order to achieve the movement of varying annual quantities of dredged material, the number

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* Mileage intervals have been arbitrarily selected for each of calculation.

of operational days per year will vary. The yearly utilization rates versus annual quantity movement are shown below:

500,000 cu yd	1,000,000 cu yd	3,000,000 cu yd	5,000,000 cu yd
14.9%	29.8%	89.3%	149.0%

Related Applications

A number of large-scale barging operations involving high capacity loading and unloading facilities are currently in operation. Selected applications are presented below.

On the east side of Hillsborough Bay in the Port of Tampa, Florida, the Eastern Barge Line is transporting about 2.25 million tons per year of phosphate rock across the Gulf of Mexico in barges to be delivered at the Freeport Sulfur Company's fertilizer chemical plant on the Mississippi River above New Orleans.[38,39] This application involves a 540-mile trip using a tow unit of one 5000-hp tug and one large 26,000-ton barge (specially designed for this application). The loading facility is a newly developed transloading facility which receives the phosphate from a unit train and transloads the material into barges.

Evansville Materials Inc., Evansville, Indiana, is involved in a dredging operation on the Ohio River to obtain sand and gravel for construction usage.[40] The material is dredged from the Ohio River, loaded into barges, and transported to Henderson, Kentucky, Tell City, Indiana, and Bridgeport, Indiana. The barge transport fleet involves 35 barges -- three 1400-ton jumbos and 32 barges of 400-ton capacity, plus two pusher boats. Barges are unloaded by a mounted crane equipped with a 2.5-yard Esco clamshell bucket on a working barge. The crane can unload a 1400-ton barge in about three hours. The clamshell is discharged into a dock hopper which feeds a 30-inch belt conveyor for transport to a transfer station above a storage bin.

The Rinkai Civil Engineering Construction Company, Ltd., of Japan is utilizing a pusher barge line system to transport fill material for coastal reclamation projects.[41] Distance traveled is

150 kilometers and the annual volume of material moved is about 1.5 million cubic yards of material. Transportation is accomplished by a barging unit consisting of one 4000-PS pusher and three 6000-cubic meter bos-type barges.

Several barging applications associated with combined rail and barge movements of coal are indicated below:

> "Although all Western coal for export currently leaves the coal field by railroad, some of it is transferred at intermediate points for final shipment by barge or ship. Commonwealth Edison receives Hanna Basin coal directly via the Union Pacific Railroad at its Waukegan and State Line power plants. However, other Commonwealth Edison plants receive Montana coal by barge via the Havana Terminal on the Illinois River. Detroit Edison will receive Montana coal via the Great Lakes Waterway. Coal shipped by Burlington Northern to a terminal near Superior, Wisconsin, will be transferred to ships for final movement over Lakes Superior and Huron to the Detroit area. Another rail-barge system is being developed by American Electric Power (AEP), who will build a coal transfer facility on the Ohio River near Metropolis, Illinois. This facility will transfer Western coal from railroad cars to barge for delivery to AEP plants on the Ohio River System. Another transloading facility has been proposed by Burlington Northern, this one to be built on the Mississippi River near St. Louis. Like the AEP transloader, this facility will have the effect of making Western coal available at many new delivery points on the inland waterway system"[18]

Cost Analysis

Barge Movement Pricing

Barge pricing varies depending upon the volume, distance, and the route to be traveled. The latter will often dictate the tow size and/or the scow size. In some cases, the waterway carrier's pricing is controlled by the Interstate Commerce Commission (ICC); however, bulk carriers are essentially exempt from ICC regulations. The following excerpt discusses this point:

> "In 1972, about 8 percent of domestic waterborne shipments measured in ton-miles were requested by the ICC. About 200 carriers have ICC rights, but only 20 to 30 use them to

transport regulated commodities. Another 150 carriers who operate exempt from economic regulations on the inland waterways are engaged in private carriage or handle only bulk shipments. The ICC has no regulating authority for these movements and a free market operates to determine charges for the exempt for line services." 35

The movement of dredged material would be considered a bulk shipment and, therefore, would not be subject to ICC regulations.

Cost Derivation Assumptions

The derivation of cost data for barge movement of dredged material inland is more complex than cost derivations for rail, truck, or belt conveyor movement because of the complex scheduling and loading and unloading process associated with barge movement. In addition to the operational assumptions specified under the technical analysis subsection, the following assumptions are specified:

a. The existing disposal area is located 1.5 miles from the mooring dock for barge loading.

b. Two barges can be loaded and/or unloaded simultaneously if required.

c. The barge loading mooring dock already exists and requires no modifications.

d. The inland disposal area is located 1.5 miles from the mooring dock for barge unloading.

e. Truck haul is utilized to move the dredged material to and from the barge mooring docks.

f. Roadways are available between the barge mooring docks and the disposal areas.

For a given actual situation one or more of the above assumptions may not hold; however, it would be very impractical to make cost derivations which would satisfy all possible situations. Therefore, for purposes of comparative analysis a typical barging application has been considered.

Barge Movement Cost Derivations

Table 6-1 presents the cost derivations for the barge loading process. These data are developed on a 24 hours per day, 280 days per year basis with a barging unit being loaded every six hours. Table 6-2 presents the cost derivation of annual fixed costs, associated with a single barging unit. Table 6-3 provides the cost derivation of the variable operating costs associated with a single barging unit operating 24 hours per day, 280 days per year. Table 6-4 presents the cost derivation of the annual fixed costs associated with the construction of a mooring dock for barge unloading. This annual fixed cost element will not vary with percent operating time per year. Table 6-5 provides the cost derivation of the annual operating costs associated with the barge unloading process. These costs are based upon a 24 hour per day, 280 days per year operational cycle.

Since all costs will vary with the operational cycle with the exception of the fixed cost associated with the mooring dock for unloading, the application and extension of these costs to a given situation (i.e., varying annual quantities over varying distances) is a relatively straightforward process of determining the yearly utilization rate (i.e., days of operation per year) and the number of required barging units to satisfy the transportation needs.

Barge Loading and Unloading Cost Summary

Table 6-6 presents a summary of the barge loading and unloading costs. These calculations are based on the postulated loading facility described previously and in Table 6-1. The total barge loading costs shown in Table 6-6 are obtained by multiplying utilization rate (defined as actual annual volume handled divided by the annual capacity of the facility) times the loading facility's total cost. For the barge unloading cost extension, the annual amortized fixed cost is applied uniformly to each volume level and the variable cost portion is calculated in the same manner as the loading costs.

Table 6-1

Annual Operating Cost Derivation - Barge Loading

Item	Description	Annual Cost
2 backhoe excavators	2 units, 24 hrs/day, 280 days/yr @ $55/hr ea	$739,200
	2 operators, 24 hrs/day, 280 days/yr @ $12/hr ea*	161,280
1 bulldozer	12 hrs/day, 280 days/yr @ $24/hr	80,640
	1 operator, 12 hrs/day, 280 days/yr @ $12/hr*	40,320
3 operational personnel	3 men, 24 hrs/day, 280 days/yr @ $9/hr*	181,440
12 15-ton dump trucks	12 units, 24 hrs/day, 280 days/yr, with driver, @ $20/hr	1,612,800
1 disposal area road *stabilization* maintenance	Gravel/roadway matting	250,000
		$3,065,680
	Estimate	$3,000,000

*Contractor overhead and fee included @ 50%.

Table 6-2

Fixed Cost Derivation - One Barging Unit

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Lay Up, Misc. Rate (%)	Annual Maintenance, Repair, Insurance, Lay Up, Misc. Charge (% x Basic Cost)	Total Annual Cost
1 1000 hp tug	$680,000	$170,000	$850,000	20	$80,232	11	$74,800	$155,032
2 1500 cu yd dump scows	1,960,000	490,000	2,450,000	20	231,256	11	215,600	446,856
								$601,888
							Estimate	$600,000

Table 6-3

Variable Cost Derivation - One Barging Unit

Item	Description	Annual Cost
Tug	Payroll (10 men @ $25,000/yr) *	$250,000
	Fuel (12 months @ $5000/month)	60,000
	Water and lubricants @ $15,000/yr	15,000
	Quarters and subsistence (10 men @ $150/month each)	18,000
	Miscellaneous tools, etc. @ $10,000/yr	10,000
2 scows (1500 cu yd each)	Payroll (2 men @ $22,500/yr)*	45,000
	Quarters and subsistence (2 men @ $150/month each)	3,600
	Miscellaneous tools, etc. @ $4000/yr	4,000
		$405,600
	Estimate	$400,000

*Contractor overhead and fee included @ 50%.

Table 6-4

Fixed Cost Derivation - Barge Unloading

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc.		Total Annual Cost
						Rate (%)	Charge (% x Basic Cost)	
1 mooring dock (500 ft @ $1000/running foot)	$500,000	$125,000	$625,000	20	$58,994	10	$50,000	$108,994
							Estimate	$110,000

Table 6-5

Annual Operating Cost Derivation - Barge Unloading

Item	Description	Annual Cost
2 barge unloading cranes	2 units, 24 hrs/day, 280 days/yr @ $55/hr	$739,200
	2 operators, 24 hrs/day, 280 days/yr @ $12/hr*	161,280
3 operational personnel	3 men, 24 hrs/day, 280 days/yr @ $9/hr*	181,440
12 15-ton dump trucks	12 units, 24 hrs/day, 280 days/yr, with driver @ $20/hr	1,612,800
		$2,694,720
	Estimate	$2,700,000

*Contractor overhead and fee included @ 50%.

Table 6-6

Allocated Cost - Barge Loading and Unloading

	Annual Volumes (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
Barge loading				
Total cost	$447,000	$894,000	$2,682,000	$4,470,000
Dollars per cubic yard	$0.89	$0.89	$0.89	$0.89
Barge unloading				
Fixed cost	110,000	110,000	110,000	110,000
Variable cost	402,300	804,600	2,413,800	4,023,000
Total cost	512,300	914,600	2,523,800	4,133,000
Dollars per cubic yard	$1.02	$0.92	$0.84	$0.83
Total loading and unloading				
Dollars per cubic yard	$1.91	$1.81	$1.73	$1.72
Allocated cost per mile (cents per cubic yard per mile)				
@ 36 miles	5.33	5.03	4.82	4.78
@ 72 miles	2.67	2.51	2.41	2.39
@ 108 miles	1.78	1.68	1.61	1.59
@ 324 miles	.59	.56	.54	.53
@ 468 miles	.41	.39	.37	.37

Given the derived loading and unloading costs, unit costs (cents per cubic yard) are calculated separately and combined for a total loading and unloading unit cost. The combined loading and unloading unit costs are constant for a specified volume movement regardless of distance the barging unit will travel. In order to arrive at a unit cost rate for loading and unloading which can be combined with the barging unit cost rate which varys with distance traveled, the loading and unloading unit cost is further allocated to a cents per cubic yard per mile rate. This allocation produces unit rates which drop significantly as distance increases, reflecting the spread of fixed handling costs over longer distances.

Barge Operation Cost Summary

Table 6-7 presents a summary of the derived barging unit costs for given annual volumes at varying distances. Extended costs are calculated by adding the amortized and the operating costs for a barging unit, multiplying this sum by the number of barging units required, and, finally, multiplying the result by the yearly utilization rate. Unit costs in both cents per cubic yard and cents per cubic yard per mile are also shown in Table 6-7 and it is observed that for a given distance, the unit cost rates will be constant regardless of annual volumes being transported. This occurs because the derived costs of a barging application at a fixed distance vary directly with the volume of material being transported. It can also be observed that unit cost rates (cents per cubic yard per mile) for a given annual volume decrease somewhat with distance traveled. This occurs because, for greater distance movements, a smaller proportion of operating time is lost due to loading and unloading activity.

Total Combined Barge Movement Cost Summary

Table 6-8 and Figures 6-3 and 6-4 provide in summary form the combined (i.e., loading, unloading, and transporting) costs associated with barge movement of dredged material for varying volumes over

Table 6-7

<u>Allocated Cost - Barge Operation</u>

	Annual Volume (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
	36 Miles (4 Units)			
Total cost*	$596,000	$1,192,000	$3,576,000	$5,960,000
$/ cu yd	$1.19	$1.19	$1.19	$1.19
¢/ cu yd/mile	3.30	3.30	3.30	3.30
	72 Miles (6 Units)			
Total cost	$894,000	$1,788,000	$5,364,000	$8,940,000
$/ cu yd	$1.79	$1.79	$1.79	$1.79
¢/ cu yd/mile	2.48	2.48	2.48	2.48
	108 Miles (8 Units)			
Total cost	$1,192,000	$2,384,000	$7,152,000	$11,920,000
$/ cu yd	$2.38	$2.38	$2.38	$2.38
¢/ cu yd/mile	2.20	2.20	2.20	2.20
	324 Miles (20 Units)			
Total cost	$2,980,000	$5,960,000	$17,880,000	$29,800,000
$/ cu yd	$5.96	$5.96	$5.96	$5.96
¢/ cu yd/mile	1.83	1.83	1.83	1.83
	468 Miles (28 Units)			
Total cost	$4,172,000	$8,344,000	$25,032,000	$41,720,000
$/ cu yd	$8.34	$8.34	$8.34	$8.34
c/ cu yd/mile	1.78	1.78	1.78	1.78

*Units x unit cost x utilization rate.

Table 6-8

Total Combined Unit Costs - Barge Movement

Cost (Cents per Cubic Yard per Mile)	Annual Volume (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
	36 Miles			
Loading/unloading	5.33	5.03	4.82	4.78
Transportation	3.30	3.30	3.30	3.30
Total	8.63	8.33	8.12	8.08
(Dollars/cubic yard)	($3.11)	($3.00)	($2.93)	($2.91)
	72 Miles			
Loading/unloading	2.67	2.51	2.41	2.39
Transportation	2.48	2.48	2.48	2.48
Total	5.15	4.99	4.89	4.87
(Dollars/cubic yard)	($3.71)	($3.59)	($3.52)	($3.51)
	108 Miles			
Loading/unloading	1.78	1.68	1.61	1.59
Transportation	2.20	2.20	2.20	2.20
Total	3.98	3.88	3.81	3.79
(Dollars/cubic yard)	($4.30)	($4.19)	($4.11)	($4.09)
	324 Miles			
Loading/unloading	.59	.56	.54	.53
Transportation	1.83	1.83	1.83	1.83
Total	2.42	2.39	2.37	2.36
(Dollars/cubic yard)	($7.84)	($7.74)	($7.68)	($7.6[illegible])
	468 Miles			
Loading/unloading	.41	.39	.37	.37
Transportation	1.78	1.78	1.78	1.78
Total	2.19	2.17	2.15	2.15
(Dollars/cubic yard)	($10.25)	($10.16)	($10.06)	($10.06)

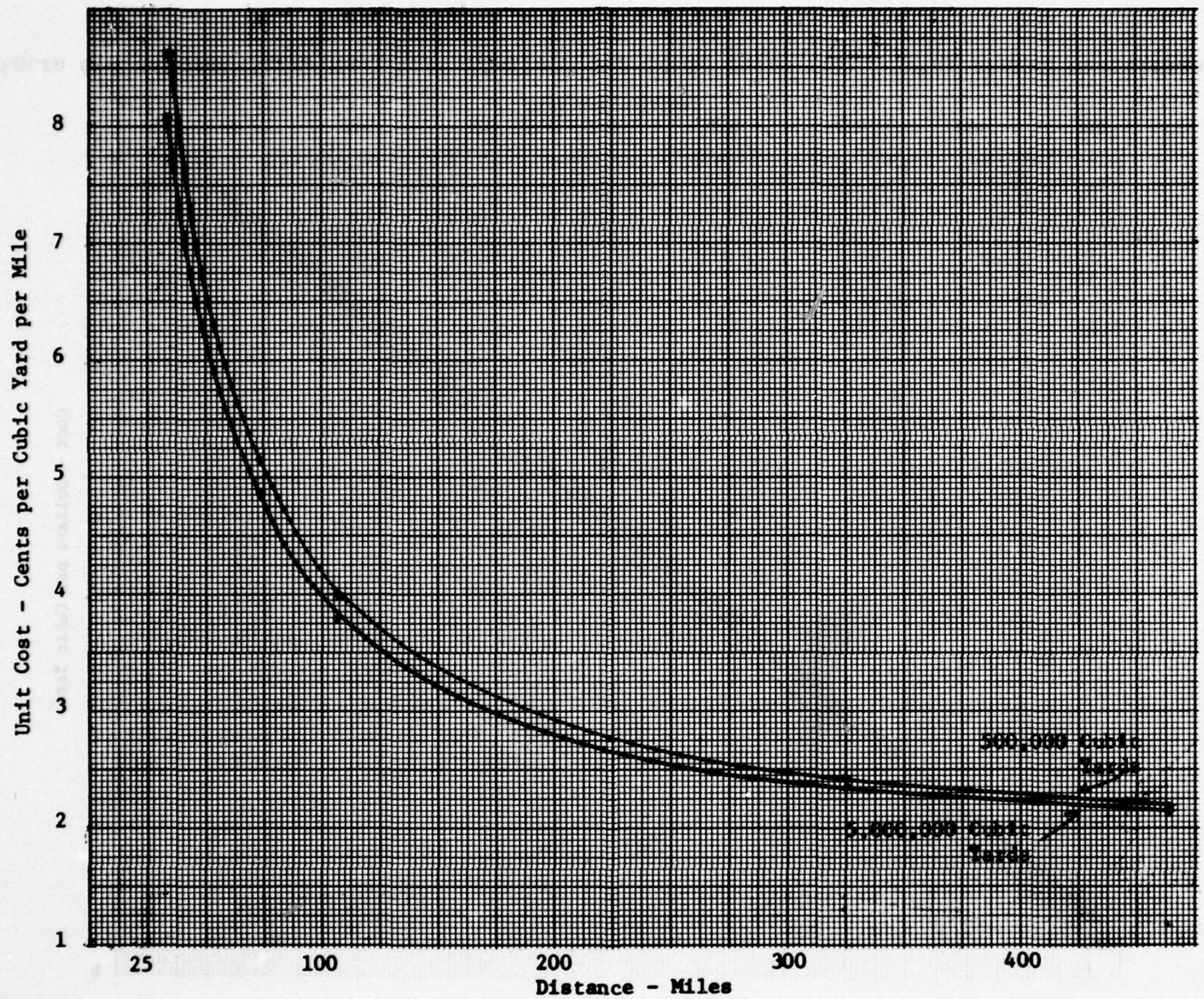

Figure 6-3. Total Barge Haul Unit Cost for Varying Annual Quantities

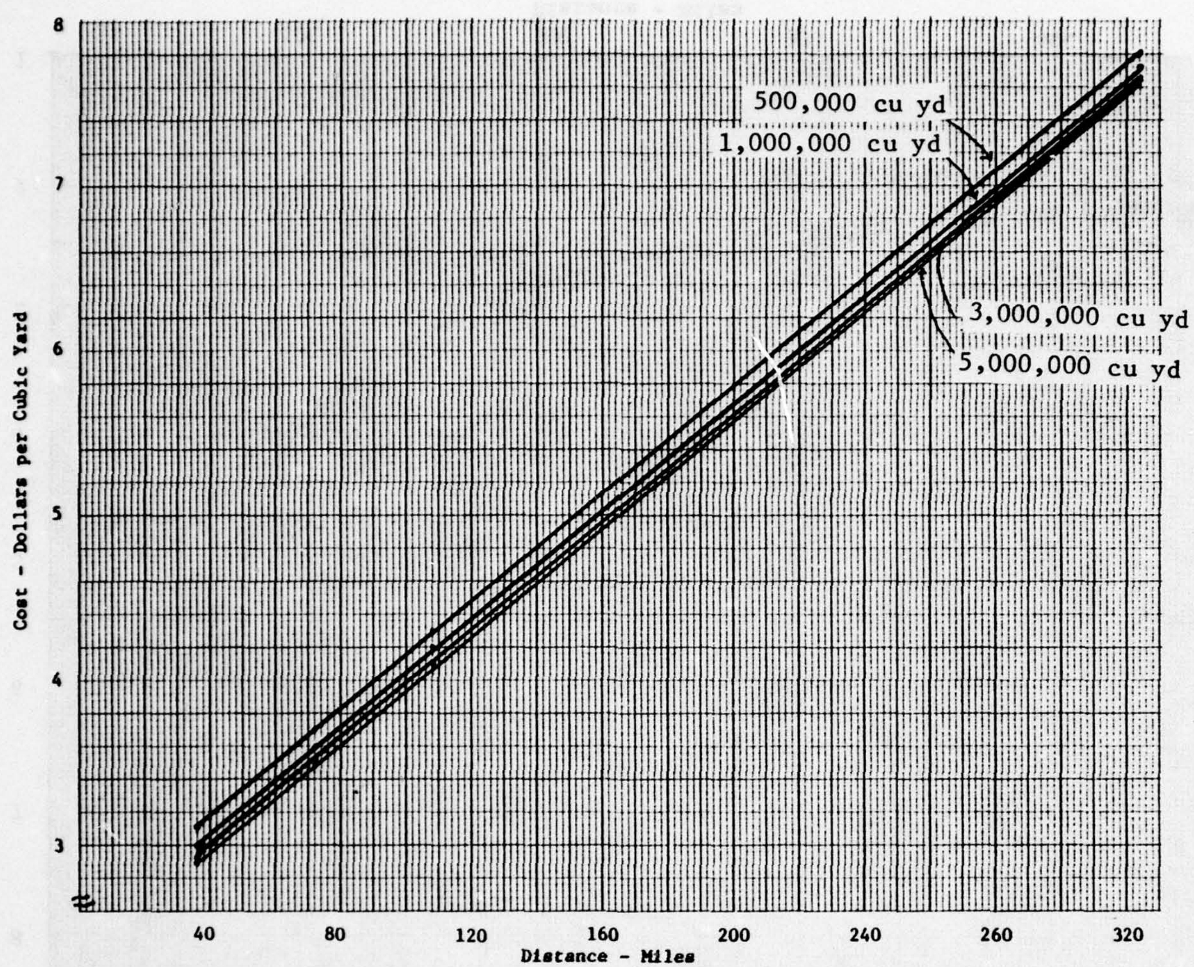

Figure 6-4. Total Barge Haul Cost (Dollars per Cubic Yard) for Varying Annual Quantities

varying distances. It can be seen from the table that loading and unloading costs dominate the combined costs for short distance movements, and that as this distance increases, the transporting cost becomes the dominating factor. This is due to the fact that the handling cost contribution drops significantly for long-distance applications as described previously. For long-distance movements where the transportation cost is dominant and constant for varying volumes, the combined unit cost rate also becomes relatively constant for varying annual volumes.

Figure 6-3 depicts the asymptotic nature of the combined unit costs (cents per cubic yard per mile) for both the short-distance movements and the long-distance movements. In the former instance, the handling cost causes the vertical asymptotic characteristics; in the latter case, the transporting cost causes the horizontal asymptotic characteristic. From Figure 6-3 it can be seen that the combined unit cost rates for barge movement vary between 2.2 and 8.6 cents per cubic yard per mile depending on distance traveled. Figure 6-4 presents the total barge haul costs in dollars per cubic yard for varying distances and volume movements.

For long-distance movements, a total rate of about 2.2 cents per cubic yard per mile is projected. In the published literature for long-distance barge hauls, rates generally fall in the range of 0.4 to 1.5 cents per cubic yard per mile.* There are several reasons why the projected rate of 2.2 cents per cubic yard per mile is higher than found in other studies. First, the 2.2 cents per cubic yard per mile rate includes loading and unloading costs which are not included in most comparative transportation studies. Secondly, the 2.2 cents per cubic yard per mile rate is based upon a fundamental tow size of two scows per tug, while other bulk haul rates are derived based upon much

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* See references 18, 33, 35, 42, 43, and 44.

larger tow sizes (i.e., 40 scows per tug, etc.). Large-size tows would have only limited application to the movement of dredged material inland because only certain inland waterways such as the Mississippi River are suitable for large tow units. Finally, the 2.2 cents per cubic yard per mile rate is based upon an average tow speed of 6 miles per hour. A greater tow speed would reduce the unit cost rate for long-distance movements. However, for many of the applications in the movement of dredged material inland, a tow speed in excess of 6 miles per hour would not be realistic.

Additional Barge Movement Considerations

If barge movement of dredged material inland proves to be a viable economic alternative for the transport of dredged material, several additional considerations should be noted prior to the final selection of barge movement as the desired transportation mode.

Nature of the Waterway

The first and perhaps most important consideration is the precise nature of the inland waterway to be utilized for barge movement. Navigable depth, speed restrictions, lock size, and traffic congestion associated with a given waterway route may potentially place limitations on the barging operation. In this regard the following quote is taken from a report to Congress by the Comptroller General.

> "Waterways industry expansion has reached a point where some main waterways arteries are becoming overcrowded. Existing lock capacities at key locations are becoming inadequate to handle all traffic. Barges must wait idly at crowded locks for long periods, resulting in severe losses of productive time."35

A further aspect of the waterway to consider is the effect of the barge traffic on recreational activities -- water sports such as boating and fishing. As an extension of this, if the barging activities cause significant disruption to recreational and/or commercial fishing activites, reaction from businesses which depend on these activities (one example being boat rental companies) would undoubtedly be forthcoming.

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Environmental Regulations

The second major consideration of barge transportation would be the possibility of leakage or spillage into waterways. This would pertain to the dredged material being handled at the loading and unloading facilities as well as the barging operation itself. An example of strict state legislation in this area was cited in the A. D. Little, Inc., study of transport of hazardous material:

> "Within the last few years...a number of coastal states have passed laws directed against industries and vessels which pollute the coastal environment. Florida, Maryland and New Jersey, for example, impose a variety of criminal fines, jail terms, and civil penalties on polluters including the requirement that polluters pay for the removal of the pollutant and the restoration of the environment. In a number of states negligence does not have to be proven, although a stricter set of sanctions is imposed if willful negligence is proven."45

> "Possibly the most stringent civil and criminal legislation has been imposed by the state of Florida. The Air and Water Pollution Control Act of 1972 calls for a penalty of $5,000 per day per offense. In addition, an offender is liable for all damage incurred, without limitation as to amount and without proof of negligence required. The regulations provide for a monetary value to be assigned to each species of fish, with an offender's liability being the total number of fish killed times the monetary value assigned to each."45

In reference to other pollution regulations, a study conducted by A. T. Kearney, Inc., for the US Maritime Commission states that:

> "More stringent air quality standards will have a complex effect on the inland marine industry. Vehicular exhaust emission regulations which are geared to divert freight to the least polluting mode will generally favor marine transportation since towboats produce fewer pollutants per ton-mile than other surface vehicles. However, such regulations could have a negative impact on truck-barge intermodal movements."44

Cook and Boyd, referring to a paper on the St. Lawrence Seaway, stated:

> "It has been calculated by the Engineering Committee of the International Association of Great Lakes Ports, for example, that ships produce 33 percent less air pollution than trains, and 373 percent less than diesel trucks in the movement of a given 1 million ton cargo. The committee's study also indicated that a ship carrying either 18,000 tons of iron ore or 5,000 tons of general cargo produced peak noises 75 percent lower than those produced by a truck operating under normal conditions or by a standing diesel locomotive."[46]

This result would tend to favor barge movement as the preferred transportation mode.

Since in many cases barge transportation would require that another transportation mode be used to move the dredged material from the unloading point to the final disposal area, constraints applicable to that transportation mode (i.e., conveyor belt, truck) would also have to be taken into consideration.

Weather Conditions

The third major consideration is the climate of the geographic area under consideration. Weather conditions can be a serious restriction to barge transport.

> "Water transportation is impossible on inland waterways during the winter months in the northern parts of the country. Navigation on the Great Lakes is at a standstill during the winter. The New York Barge Canal is open about seven months of the year...Water transportation upon improved rivers is often interrupted by floods or drought. This difficulty has frequently been experienced on the Mississippi River System."[47]

As in the case of rail and truck haul in open-topped cars and trucks, both freezing temperatures and excessive rainfall will influence the material handling quantities of the dredged material being transported. Because of these reasons, each application must be examined to evaluate the impacts resulting from adverse climatic conditions.

User Charge

A final consideration which, although not currently in effect, could potentially alter the economies of barge movement is the possibility that a user charge could be enacted by the Congress as a means to finance continued maintenance and/or improvements to the inland waterway system.[35] In a 1975 Comptroller General report to the Congress, the possibility of enacting a waterways user charge is discussed in considerable detail. At this time it is difficult to determine the mood of the Congress with regard to this proposal; however, at some time in the future it is likely that the issue will come before the Congress for definitive decision.

PART VII: TRUCK HAUL ANALYSIS

General

Although truck haul of large volumes of bulk material over long distances is generally uneconomical when compared to rail and barge movements, truck haul for shorter distances could be an economical choice for the transport of dredged material. Truck haul has the particular advantage of geographic flexibility which often limits consideration of other transportation modes. In general, truck haul is a "door-to-door" operation which does not require elaborate and excessively expensive loading and unloading facilities. Truck haul is also a relatively fast mode of transportation over short and intermediate distances.

The following quote provides a representative profile of the trucking industry.

> "Although the trucking industry is organized differently from the railroad industry, the range of services offered is approximately the same. The geographical availability of trucks is greater than that of any other mode. Also a truck frequently performs at least a part of the service provided by other types of carriers. This, of course, is because the highway virtually begins at the shipper's door and there are more miles of it than of any other transport way. There are about three and one-half million miles of roads and streets in the United States. Much of this mileage provides the service of providing access to farms and to residential property so that, of the total, approximately 570,000 miles can be considered as providing a basic intercity transportation system. Over this network, more than 16,000 interstate, for-hire trucking companies now carry more than 140 billion ton-miles of freight annually. In addition, twice this amount is carried by intrastate, non-regulated and private truckers. The extent of intrastate trucking operators who do business only within a particular state is surprisingly large. Research experience indicates

that California, for instance, has about fifteen thousand intrastate trucking permits in force in any given year; many less extensive states generally have between one thousand and three thousand local companies in operation. The American truck fleet is correspondingly large. Approximately twelve million truck-type vehicles are presently registered in the various states. Over half of these, however, are light vehicles having gross weights of less than 10,000 pounds. About one million trucks are operated by the for-hire carriers."[48]

Technical Analysis

Truck Haul Options

The options associated with truck haul of dredged material are primarily concerned with truck size and truck type. The larger the truck capacity the more economical the truck hauling of bulk material will be. However, both the Federal Government and individual states place restrictions on the size and weight of trucks for open road usage.

"Because of the impact of trucking costs upon our economy, there has been strong pressure for an upward adjustment in our size and weight laws over the years. Since the responsibility for such regulations lies primarily with the states, progress has been spotty. In 1956, a further complication was added. The Federal Government adopted a set of maximum size and weight regulations. These Federal regulations were prohibitive rather than permissive. That is, the Congress placed a ceiling upon the size and weight of vehicles that the states could allow to use the National System of Interstate and Defense Highways, but did not require that the states permit vehicles of that size to use the system. Thus, any state that wishes to can restrict vehicles to sizes and weights below the Federal limits, but none can allow vehicles to operate upon the Interstate System that exceed the Federal standards."[49]

"Size and weight regulations generally cover the width, height and length of vehicles. Sometimes these regulations also cover the types of combinations that may be operated as well as the dimensions of their components. Weight regulations usually cover the amount of weight that can be carried on single and tandem (two axles grouped together) axles, and the maximum amount that can be carried on vehicles and combinations. Most often the overall or gross weight is related to wheel bases."[49]

"Single axle loads vary from 18,000 to 22,400 pounds with the heavier axle loads tending to be grouped in the northeastern states. Tandem axle loads show a much greater range varying from 3,000 to 40,680 pounds. The gross vehicle weight restrictions range from a maximum of 60,000 lbs. in one state to 100,000 lbs. in another, with most having limits between 70,000 and 75,000 lbs. Michigan has no gross weight limit, its law being based on axle loads only. There are so many special provisions relating to size and weight limitation that space will not permit discussion of all of the variations." 49

The options relative to truck type for the movement of bulk material are essentially open-topped dump trucks or tank-type trucks. Dump trucks are very commonplace, while the tank-type truck has only recently become popular in hauling of bulk materials such as ready-mix cement and other related products. The tank-type truck is fully enclosed and is loaded and unloaded pneumatically. The time for loading and unloading is considerably longer than the dump truck; however, the material is not exposed to the weather which is an advantage in many instances. Each type of truck is capable of transporting loads in the 25-ton range.

Generalized Truck Haul System

For the transportation of large annual volumes of dredged material over distances up to 150 miles, open-topped, 25-ton dump trucks will be utilized. The advantage of rapid loading and unloading with open-topped dump trucks is believed to be more desirable than the handling procedures associated with tank-type trucks. Additionally, the open-topped dump truck is the more commonplace truck for movement of construction aggregate, bulk materials.

The 25-ton size dump truck is the largest size open road truck available which will be compatible with most state regulations for truck hauling. Some states have greater highway weight limits; however, in general a net weight limit of 50,000 lb is followed by most trucking companies. For dredged material which is assumed to have a

weight of about 100 pounds per cubic foot (i.e., close to that of sand), a 25 net ton load will equal about 18.5 cubic yards of material per truckload. Since the weight of the dredged material is relatively high, the truck size limitation is not significant in comparison to the weight limitation. It should be noted that in those instances where secondary roads must be traveled, care must be taken to ensure that bridges and roadways will permit truckload capacities of 25 net tons. If in fact restrictions exist on a given route, either smaller trucks will have to be utilized or other perhaps longer routes will have to be taken.

The operational cycle of a given truck will depend on the distance over which the material must be handled and the time required for loading.

Loading and Unloading Facilities

The typical loading facility for truck haul is based upon a simplified version of the rail loading facility (refer to Part V Figure 5-1). The excavation of the existing disposal area involves the use of two backhoe excavators which load a portable belt conveyor. The portable belt conveyor loads a fixed belt conveyor which moves the material out of the disposal area into feedout bins utilized to load the trucks. At the end of the fixed conveyor belt a shunting arrangement is planned to load either of the two feedout bins, and as one bin becomes full, the material will be shunted to load the other bin. In this manner each bin with a capacity of 100 cubic yards can load trucks simultaneously, and the loading operation will not be directly dependent on the excavating operation.

The operational loading cycle is as follows:

- Material flow on the fixed belt conveyor is at 740 cubic yards per hour.
- Truck capacity is 18.5 cubic yards.
- Time to load one truck is three minutes.
- Two trucks are loaded simultaneously.

- In a 24-hour day, 960 truckloads are loaded resulting in 17,760 cubic yards of material per day.

The unloading procedure at the distant disposal area requires no facilities and involves back dumping of material within the distant disposal area. Time to unload is about three minutes.

Truck Operational Cycle Time

As described in the previous section, the truck loading time is three minutes and two trucks are loaded simultaneously. The truck unloading time is estimated to be three minutes. The estimated average speed for truck transportation is thirty miles per hour which is based upon relatively good roads. If extensive use of secondary roads is required, this average speed would, most likely, be reduced. Based on the above conditions and a 24-hour operational day, the following total truck haul round-trip cycle time is estimated for varying distances:

Miles (point to point)	Time (Hrs) Loading & Unloading	Travel	Total	Loads/Day Per Truck	No. of Trucks Required	Annual Cubic Yards Moved per year @ 280 days/yr
30	.1	2.0	2.1	11.4	85	4,972,800
60	.1	4.0	4.1	5.8	166	4,972,800
90	.1	6.0	6.1	3.9	247	4,972,800
120	.1	8.0	8.1	3.0	320	4,972,800
150	.1	10.0	10.1	2.4	400	4,972,800

The data shown above indicates the number of trucks required to sustain a continuous three minute loading operation for varying hauling distances. At this rate nearly 5 million cubic yards will be transported each year. For lesser volume movements under consideration, the number of days of operation will be reduced, and the resultant yearly utilization rates are:

500,000 cu yd	1,000,000 cu yd	3,000,000 cu yd
10%	20%	60%

Since truck hauling costs (exclusive of loading costs) are directly variable with operational usage, smaller annual volume movements can be developed by considering the use of fewer trucks or by applying the above utilization rates. For ease of calculation, the utilization rate method has been selected for the cost extensions provided in later subsections.

Related Applications

The number of identified applications of truck haul for the transport of large annual volumes of bulk material are limited. However, two related applications are discussed briefly to provide examples of both a sustained trucking operation and an efficient loading process.

In the first instance a sustained trucking operation has been utilized to supply coal to the Illinois Power Company at the Vermillion Power Station.[33] The coal is supplied from the Zeigler Coal Company's Murdock Mine, which is 48 miles away from the power station. Coal is transported by 20-ton trucks.

In the second instance, phosphate ore is hauled from Monsanto's Henry Mine near Soda Springs, Idaho, to the company's phosphorus plant about 15.5 miles away.[50] Although the application involves the use of much larger trucks, the operating cycle is a 19-hour day and involves two automated 165-ton triple feeder bins to load the trucks in a time of 1.75 minutes. The average truck speed is 30.4 mph and two minutes is allowed for dumping. This application provides a good example of the operational cycle associated with large-volume bulk material movement by truck haul.

Cost Analysis

Truck Haul Pricing

In the trucking industry there are basically three types of carriers which operate motor trucks over the highways: common carriers, contract carriers, and private carriers. The first two carriers are

for hire and the third type of carrier involves individuals or businesses which transport their own product. Common carriers may be further subdivided into regular-route carriers and irregular-route carriers.

Regular-route carriers carry general freight and are open to the public for all types of freight. These freight lines accept shipments on a bill of lading much the same as of railroads.

Irregular-route carriers are described below:

> "Perhaps greater in number are common carriers with irregular route, nonradial operating authorities. These operators usually can haul a few categories of goods such as heavy machinery or building materials. They are permitted to use the necessary highways between specified cities or groups of communities. Some carriers are allowed to operate over territories which may include several states. Colloquially know as call and demand operators, they carry only full truckload consignments, preferably of a reasonably regular traffic. They have almost no terminal cost and can offer an attractive scale of rates to shippers who can use them. Although carriers of this sort were originally intended to be common carriers of only specific commodities, they are tending to expand their operating rights. They do this by applying for additional authorities to haul heavy one commodity traffics which they discover. These are often granted because the request to haul one commodity does not appear to threaten the market of the general commodities carriers. Also the specialized irregular carriers tend to follow or establish routes different from those of general freight haulers."48

Common carriers generally fall under the regulating jurisdiction of the Interstate Commerce Commission. Regulation is usually referred to as economic regulation which means that all rates must be published and that the same prices must be charged to all like customers. There are, however, four types of motor service where the rate depends on negotiation between the carrier and the shipper. These are local cartage, exempt carriers, contract carriers, and private carriers. Basically the first two are spin-off forms of the common carrier category.

Local cartage.

"Even the smallest cities in the United States domicile truck operators who specialize in performing hauling and delivery within the immediate area of the municipality. Large cities usually have many of these firms which are referred to as transfer companies, or as transfer and storage companies....Since the Interstate Commerce Commission has not exercised its power to regulate the thousands of carriers in this category, rates for their services often may be negotiated. In many cities, however, local cartage rates are closely regulated by the state, and tariffs are published which apply to all alike."48

Exempt carriers.

"Certain interstate trucking activities are exempt from the economic control of the Interstate Commerce Commission. This means that rates for their services are completely open to negotiation between carrier and customer. Altogether, there are eleven categories, or classes of exempt carriers, among which are the following:

1. A person (or company) may carry his own goods in his own truck in interstate commerce.
2. An agricultural cooperative association (or federation of such associations) may engage in interstate, for-hire carriage of property between its suppliers, warehouses and outlets.
3. Motor vehicles used in carrying property consisting of ordinary livestock, fish or nonmanufactured agricultural or horticultural commodities on a for-hire basis in interstate commerce are wholly exempt from economic regulation.
4. Any person not engaged in motor transport as a primary business may perform casual, occasional or reciprocal for-hire interstate transport for others.

...In addition to this carriage of exempt commodities by carriers not subject to economic regulations, transportation of agricultural goods may be performed by regulated common or contract for-hire carriers as long as they do not place them in the same vehicle with regulated goods. In effect, exempt commodities become nonexempt when carried in a mixed load with commodities subject to regulations."48

Contract carriers.

"The shipper may haul his own goods in his own trucks which is referred to as private carriage, or he may make a long-term contract with someone else who has a truck to do his trucking for him. The latter is now known as contract carriage and has led to the development of a special type of trucking company which serves only a limited number of customers and does not hold itself out to the general public. To prevent such companies from hauling for everyone and competing unfairly with common carriers, they are subject to regulation by the Interstate Commerce Commission (and by most state regulatory commissions). Thus, a contract carrier must obtain a permit from the I.C.C. before he can do interstate business. Although he is allowed to discriminate among customers and charge them different amounts, a schedule of the lowest actual rates he charges as well as a copy of each of his contracts must be on file with the I.C.C. There are more than two thousand six hundred operators which presently hold interstate contract carrier permits and many more which operate wholly within individual states. Because no terminal facilities are maintained and because a steady traffic is assured, contract carrier rates are often lower than those of common carriers serving the same area. Also, due to his continuing relationship with the customer, the contract trucker's service can be somewhat special. Drivers do not need to be instructed continually in such matters as where to find the goods; service such as moving freight into the warehouse and stacking it may be performed in addition to transportation. The contract carrier is a useful alternative for the traffic manager, although he is not as easy to locate as the common carrier. Also, the operating authority and regulatory status of the carrier should be checked carefully by the new customer since the management of some of these carriers is not performed by experts."[48]

It is obvious from the above variations on truck hauling that it is difficult to make a clear cut choice of which type of carrier would be utilized for transporting dredged material. This fact, in turn, complicates the costing of a typical trucking application. However, given the above alternatives that are available for truck haul, the most probable options for the movement of dredged material are common carrier local cartage, common carrier exempt, and contract carrier.

The cost data utilized for truck haul is based upon estimates provided by two large common carriers who are primarily engaged in bulk material movements.

Cost Derivation Assumptions

The majority of the assumptions associated with costing the truck haul alternatives have been discussed in the previous subsections. Additional costing assumptions are provided below:

- Roadways are directly available at the existing disposal area and at the distant disposal area. These roadways are capable of handling 25-ton trucks.
- No maintenance or upgrading of roadways is required.
- Truck haul will be performed by a trucking company and rates will be established on a negotiated basis.
- Truck rates are fully loaded and include all associated driver and fuel costs.

Cost Derivations - Truck Loading and Unloading

Table 7-1 presents the fixed cost derivations associated with the truck loading facility. These fixed costs are amortized over a 20-year economic life and are costed at the full amortized value regardless of the yearly utilization rate. Table 7-2 provides the derivation of the variable costs associated with the truck loading operation. These data are derived based upon a 280 days per year, 24 hours per day operational cycle. Table 7-3 presents a summary of the combined allocated truck loading costs on both a cents per cubic yard basis and a cents per cubic yard per mile basis for varying annual volume movements. These data depict the typical characteristic of high unit costs for short-distance movements and for low annual volumes, and low unit costs for longer distance movements and larger annual volumes.

As described earlier, no costs are associated with the truck unloading operation.

Table 7-1

Fixed Cost Derivation - Truck Loading Facility

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc. Rate (%)	Annual Maintenance, Repair, Insurance, Security, Misc. Charge (% x Basic Cost)	Total Annual Cost
2 portable feeder bins for belt conveyor (5 cu yd ea @ $10,000 ea)	$20,000	$5,000	$25,000	20	$2,360	32	$6,400	$8,760
1 portable belt conveyor (40" belt, 1000 cu yd/hr, 1250 ft length @ $400/ft)	500,000	125,000	625,000	20	58,994	27	135,000	193,994
1 fixed belt conveyor (40" belt, 1000 cu yd/hr, 3500 ft length @ $400/ft)	1,400,000	350,000	1,750,000	20	165,183	18	252,000	417,183
2 feedout bins (100 cu yd ea @ $150,000 ea)	300,000	75,000	375,000	20	35,396	32	96,000	131,396
								$751,333
							Estimate	$750,000

Table 7-2

Variable Cost Derivation - Truck Loading Operation

Item	Description	Annual Cost
Disposal area excavation	2 backhoe excavators, 24 hrs/day, 280 days/yr @ $55/hr ea	$739,200
	2 backhoe operators, 24 hrs/day, 280 days/yr @ $12/hr*	161,280
Facility operations	4 men, 24 hrs/day, 280 days/yr, @ $9/hr*	241,920
	1 bulldozer, 8 hrs/day, 280 days/yr, @ $24/hr	53,760
	1 bulldozer operator, 8 hrs/day, 280 days/yr @ $12/hr*	26,880
Electric power	400 hp @ 24 hrs/day, 280 days/yr @ $.0157/hp hr	42,202
		$1,265,242
	Estimate	$1,270,000

*Includes contractor overhead and fee @ 50%.

Table 7-3

Summary of Truck Loading Costs

Item	Annual Volume (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
Utilization percent	10	20	60	100
Fixed yearly cost ($000)	750	750	750	750
Variable yearly cost ($000)	127	254	762	1,270
Total yearly cost ($000)	877	1,004	1,512	2,020
Dollars per cubic yard	1.75	1.00	0.50	0.40
Allocated cost per mile (cents per cubic yard per mile)				
@ 30 miles	5.83	3.33	1.67	1.33
@ 60 miles	2.92	1.67	.83	.67
@ 90 miles	1.94	1.11	.55	.44
@ 120 miles	1.46	.83	.42	.33
@ 150 miles	1.17	.67	.33	.27

Cost Derivation - Truck Haul

Figure 7-1 presents a cost estimating curve of truck haul unit costs (cents per cubic yard per mile) versus point to point distance of a typical large volume movement of dredged material. This curve represents an average of three estimated truck haul profile rates provided by two large bulk haul trucking companies. The estimates rates provided by the trucking companies were not firm quotations but they were selected based upon the following.

- Transportation of relatively dry dredged material in open-topped dump trucks.
- Annual volumes in the range of 500,000 to 5,000,000 cubic yards per year.
- An operational cycle of six days per week, 24 hours per day.
- No toll charges included.
- Rates were point to point rates with empty return contemplated.
- Approximate net weight per truck of 25 tons.

At the prescribed range of annual volume movements indicated above, no variations in rates within this range were expected. Each estimated rate profile, although representing different geographic areas of the country, was selected by the trucking companies for their overall representativeness. The variation between the estimated rates and the average rate depicted in Figure 7-1 for very short distance hauls (i.e., 10-20 miles) was in the order of ± 33%. For longer distance hauls of one hundred miles, the variation in estimates were less than ± 10%.

Therefore, two factors must be considered when utilizing the unit cost data presented in Figure 7-1. The first is that this curve represents an estimated average rate and, for specific transportation applications, these rates will vary depending upon the geographic location and the trucking company selected. Secondly, the truck haul rates for short-distance movements will vary more widely depending upon the specific application.

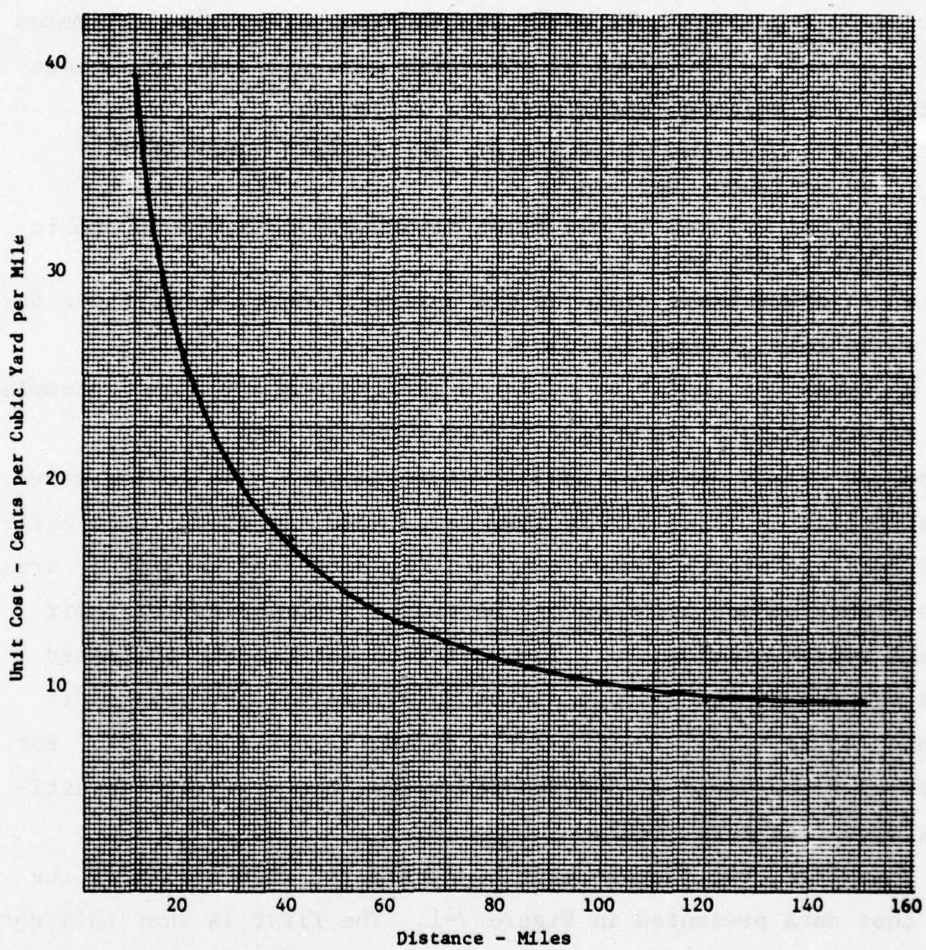

Figure 7-1. Truck Transportation Rates vs Distance (Exclusive of Loading/Unloading Cost)

A final consideration in the utilization of these rates is that each specific application will involve a negotiated rate with a given carrier, and where competition is strong in the trucking industry and/or where a specialized contract carrier is available, lower rates may be found.

The unit cost curve presented in Figure 7-1 indicates the typical curve shape found for other transportation alternatives, that is, higher unit cost for short-distance movements and an asymptotic lower unit cost for longer-distance movements. For distance movements in excess of 100 miles, an asymptotic unit cost of about 9.2 cents per cubic yard per mile is found. In a couple of instances, studies[33,44] found in the literature indicate that truck haul rates can be in the range of 2.7 to 5.1 cents per cubic yard per mile; however, these rates do not include loading and unloading costs and recent inflationary adjustment factors (i.e., rising fuel costs). In particular, the type of motor carrier utilized, the geographic location, the commodity being carried, and adjustments for recent labor and fuel cost increases will affect the expected rate for a given movement. Based on these factors, some of which are unknown in relation to the above studies, it is believed that the rates depicted in Figure 7-1 are the most representative for a typical truck haul application.

Total Truck Haul Cost Summary

Table 7-4 and Figures 7-2 and 7-3 present the total costs (loading, unloading, and transportation) for truck haul of dredged material inland. Table 7-4 provides a detailed breakout of unit costs (cents per cubic yard per mile) for varying mileages and for varying annual volumes. It can be observed that unit transportation rates for varying volumes are constant at given distances, while material handling costs drop sharply. Additionally, for given annual volumes, both material handling and transportation costs will drop toward an

Table 7-4

Total Combined Unit Costs - Truck Haul

Cost (Cents per Cubic Yard per Mile)	Annual Volume (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
	30 Miles			
Loading/unloading*	5.83	3.33	1.67	1.33
Transportation	20.00	20.00	20.00	20.00
Total	25.83	23.33	21.67	21.33
(Dollars/cubic yard)	($7.75)	($7.00)	($6.50)	($6.40)
	60 Miles			
Loading/unloading	2.92	1.67	.83	.67
Transportation	13.20	13.20	13.20	13.20
Total	16.12	14.87	14.03	13.87
(Dollars/cubic yard)	($9.67)	($8.92)	($8.42)	($8.32)
	90 Miles			
Loading/unloading	1.94	1.11	.55	.44
Transportation	10.70	10.70	10.70	10.70
Total	12.64	11.81	11.25	11.14
(Dollars/cubic yard)	($11.38)	($10.63)	($10.13)	($10.03)
	120 Miles			
Loading/unloading	1.46	.83	.42	.33
Transportation	9.70	9.70	9.70	9.70
Total	11.16	10.53	10.12	10.03
(Dollars/cubic yard)	($13.39)	($12.64)	($12.14)	($12.04)
	150 Miles			
Loading/unloading	1.17	.67	.33	.27
Transportation	9.50	9.50	9.50	9.50
Total	10.67	10.17	9.83	9.77
(Dollars/cubic yard)	($16.01)	($15.26)	($14.75)	($14.66)

*Unloading costs are assumed to be negligible.

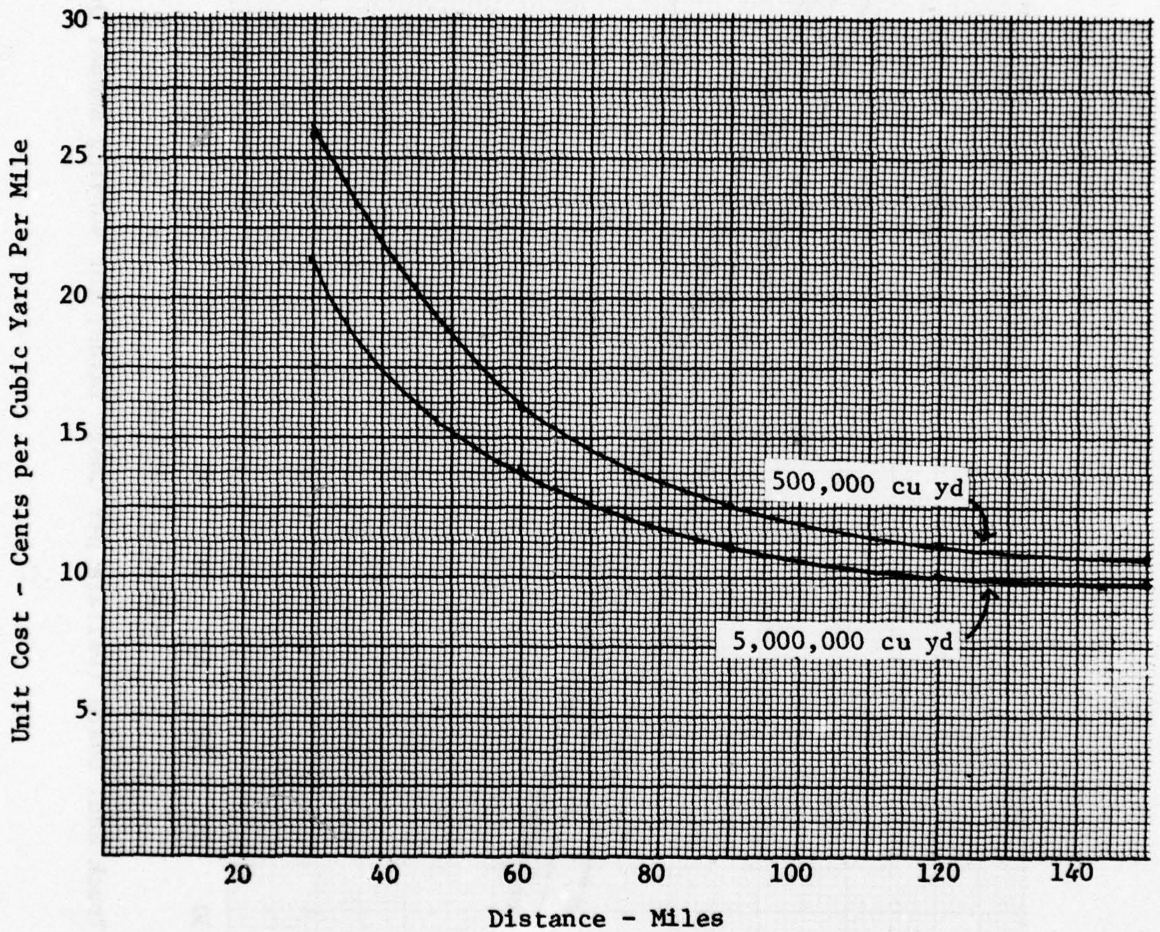

Figure 7-2. Total Truck Haul Unit Costs for Varying Annual Quantities

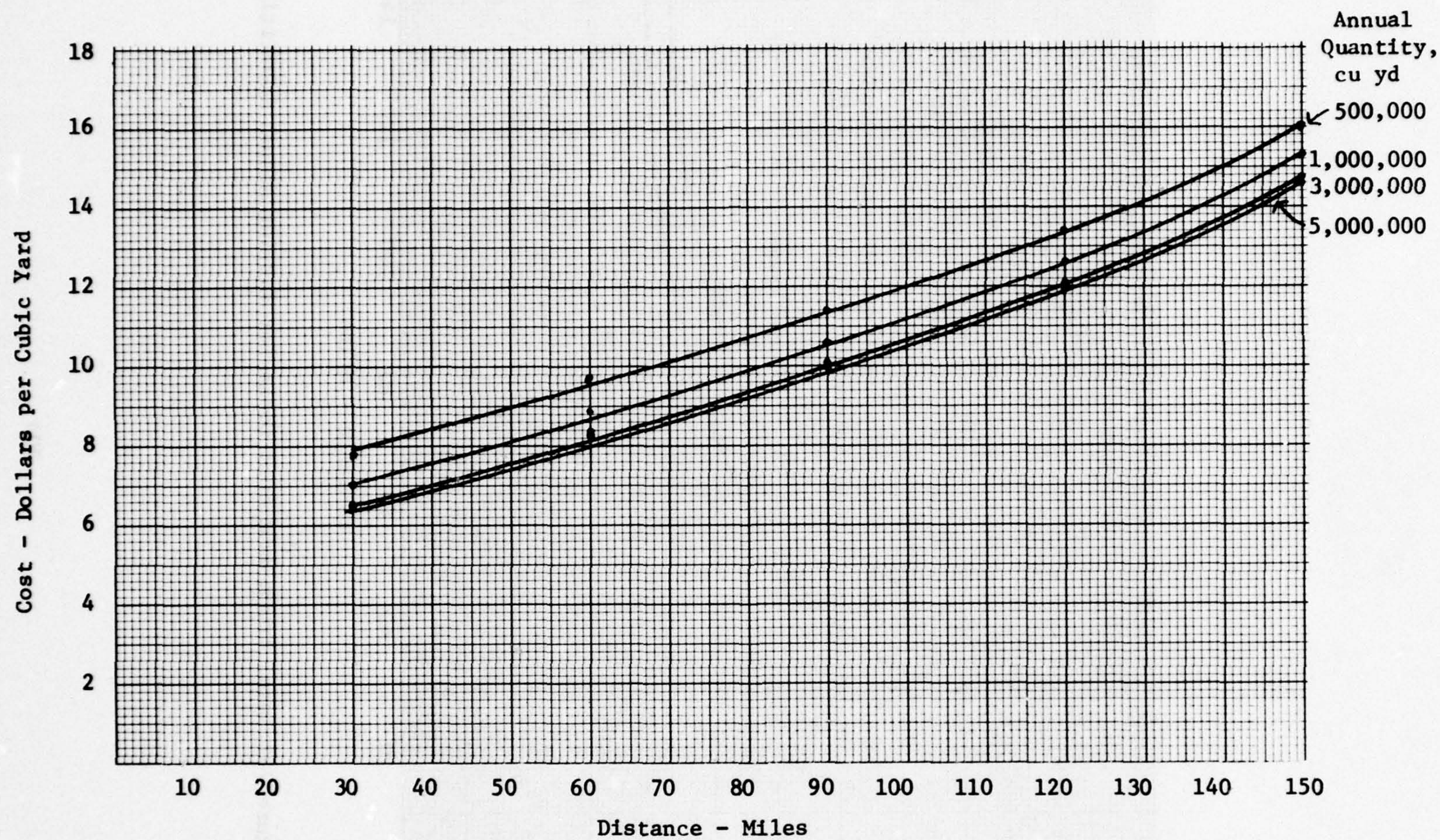

Figure 7-3. Total Truck Haul Costs (Dollars per Cubic Yards) for Varying Annual Quantities

asymptotic value as distance increases. Figure 7-2 depicts in graphic form the unit costs reflected in Table 7-4. Figure 7-3 presents the unit costs for truck haul in dollars per cubic yard for varying distances and annual quantities.

Additional Truck Haul Considerations

Given the economic suitability of the truck haul alternative for the movement of dredged material, the following considerations should be examined to insure that potentially unforeseen circumstances are not overlooked. Two general types of regulations which should be examined are regulations to protect the highway and safety regulations.

> "...Under the first type of regulation are the weight limitations imposed upon vehicles to prevent destruction of bridges and road surfaces....Although it is conceded that regulation of this type is desirable, there is frequent controversy over just what restrictions should be imposed..."[47]
>
> "Weight limitations are of various types. Gross weights may be fixed in order to limit the weight of the load as a whole; maximum weights per axle or per wheel may be used to limit the concentration of loads; and weight per inch of tire width may be used to assure that vehicles are equipped with tires of sufficient size to sustain the load without damage to the highway."[47]

Some states have been much more strict in limiting weights of vehicles than others. The diversity in state requirements relating to maximum weights of motor vehicles has been a handicap to long-distance transportation by motor vehicle that must cross state boundaries.

> "A certain degree of Federal control over weight limits was provided by the Federal Aid Highway Act of 1956 so far as the National System of Interstate and Defense Highways is concerned."[47]
>
> Included in the safety type regulation
>
> "are the numerous measures designed to protect the general users of the highway. These measures specify limitations on width of trucks and buses; maximum heights; maximum lengths of vehicles

and of combinations of vehicles; speed limits; requirements to insure the equipment of vehicles with safety appliances such as speedometers, adequate brakes, horns, lights, windshield wipers, mirrors, and bumpers. Under this type of regulation also is included the requirement that motor-vehicle operators carry liability insurance against personal injuries and property damage caused in the operation of vehicles."[47]

The main health regulations include air pollution controls on vehicle exhaust emissions under the Clean Air Act of 1970 and the vehicle noise emission standards under the Noise Control Act of 1972.

"The air quality impacts associated with land disposal of dredge spoils would be caused by fugitive dust losses and any on-site heavy equipment vehicle use....It may be desirable to move the material after initial placement. If this is to be done using heavy duty equipment, the vehicle emissions could be substantial depending on the number of vehicles needed. Vehicle activity on the site would also increase dust losses due to added surface disruptions."[9]

Various local ordinances also place restrictions on truck transportation. These include restrictions on hours of day and roads to be used for trucks, and particular noise and traffic restrictions in areas such as hospital zones and residential neighborhoods.

In the Craney Island Disposal Study,[8] one consideration was that of transporting material via truck haul to borrow pits. Among the problems in the implementation of this plan was that an estimated 1,000 (12 cubic yards) truck loads based on operating on a 16-hour, 6-day week schedule would be utilized to move the annual input of 3.8 million cubic yards of dredged material.

"Impacts of this substantial volume of traffic on the condition of existing highway systems, and safety of everyday highway users must be considered detrimental."[8]

In the final environmental statement for Diked Disposal Island, Hart and Miller Islands, Baltimore County,[10] consideration was given to use of trucks for transporting dredged material from railroads to strip mine areas in western Maryland.

"Normally truck loads are approximately 5 cubic yards per trip, which means that about 10,000,000 trips would be necessary to

> transport 50 million cubic yards from the material storage area to the railroad, and from the railroad to the strip mine sites. Such a heavy usage of highways can be expected to necessitate highway improvements and nuisance conditions from the truck traffic."[10]

In addition, the San Francisco Bay Dredge Disposal Study[9] pointed out the fact that the coordination of a large number of trucks through urban traffic would be extremely difficult.

An example of the general type of problem which might be expected, particularly in a project involving a heavy concentration of truck transportation was cited by Reikenis:

> "Sand and gravel operations all over the country have in recent years begun to feel the pressures...of the trend toward environmental protection. Large populations moving from cities into suburban areas have pre-empted by development much land intended for future production of sand and gravel resources. The presence of these people in the suburban areas near operational centers has increased the pressures to restrict operations. Frequent objections include the hazards of truck traffic, noise and dust, and the unsightly nature of the excavations."[15]

One of the particular problems associated with truck transport of dredged material is the possibility of spillage. This would be a problem in the case of an accident requiring extensive cleanup.

As is the case with other modes of transportation, weather conditions will place restrictions on truck transportation, particularly in northern states where snow and ice create hazardous driving conditions.

PART VIII: BELT CONVEYOR ANALYSIS

General

The typical application for belt conveyor movement of bulk materials is associated with providing an efficient material handling capability. Historically belt conveyors have been used in mining operations and for transporting material relatively short distances (up to 1000 feet). However, recent technological improvements of belting materials have led to many uses of belt conveyor systems as a primary transportation mode for the movement of bulk materials over distances of up to about ten miles. In one instance, a belt conveyor system is now operational over a distance of sixty-two miles.

In examining the options for the movement of dredged material in a relatively dry state, belt conveyor transportation must be considered an alternative on a technical basis if not also on an economic basis. Belt conveyor transportation has several unique advantages and also has a number of limitations. The basic advantages of belt conveyor transportation are:

- low operating costs
- high volume movements
- minimal noise and air pollution impact
- no disruption of highway traffic
- not dependent on waterways and/or rail lines being in place

Overall, belt conveyor systems are a very efficient means for moving large quantities of bulk material.

The disadvantages of belt conveyor transportation are:

- high initial investment cost
- potential unavailability of right-of-way

Overall, given an application where the right-of-way is available and existing road, rail, and waterway routes are not available or are less than desirable, belt conveyor transportation could be the selected mode for the movement of dredged material inland.

Technical Analysis

Belt Conveyor Options

Belt conveyor systems are generally defined by the size of the belt, the length of the system and the throughput of the system in tons per hour. For the movement of bulk material, belts vary in size from about 30 inches to about 72 inches in width. Obviously, the larger the throughput requirement, the wider the belt. For material movements of 1000 tons per hour, the belt width usually varies anywhere from 36 inches to 48 inches. For larger capacity systems where high volumes are required, 72-inch belt widths are common. For the movement of bulk materials, the sides of the belt will be troughed at an angle to contain the material on the belt. The troughing angle can vary anywhere between a 20^{o} to 35^{o} angle. The larger the angle the greater the carrying capacity.

Long-distance conveyor systems are generally found by putting together a series of conveyor flights. Individual conveyor flights vary from 900 feet to 26,400 feet in length depending upon the terrain being traversed. Level terrain will permit long flight lengths because power is not required to lift the material over elevations.

The throughput of a belt conveyor system is based upon the speed and capacity of the belt. While the speed of a belt conveyor can be increased by additional horsepower to the drive motors, practical limits must be observed. The usual speed of a belt conveyor for bulk materials is between 7-10 miles per hour.

Generalized Belt Conveyor System

For the purposes of transporting dredged material inland over distances ranging from 6 to 60 miles, the following generalized system

is defined. The throughput requirement in cubic yards per hour will be approximately 74 cubic yards per hour (about 100 tons per hour) for each annual volume increment of 500,000 cubic yards. This throughput requirement is based upon a 24 hours per day and 280 days per year operational cycle. Since the major cost associated with a belt conveyor system is its high fixed investment cost, a continually operating system is essential to achieve economies of operation.

The belt width for a given application will be based upon the throughput requirement, and probable sizes for varying requirements are provided below:

Item	Annual Volumes (cu yd) 500,000	1,000,000	3,000,000	5,000,000
Throughput (tons/hr)	100	200	600	1000
Belt width (inches)	30	30	36	40
Drive horsepower	150	200	300	400
Average flight length (miles)	2	2	2	2
Belt speed (miles/hr)	6	12	10	10

Most bulk material belt conveyor systems today are covered or fully enclosed from the weather. Since this cost element is relatively small in comparison to other system costs, a covered belt conveyor system would most likely be utilized.

In general when purchasing a belt conveyor system, a prime contractor is selected to design and install the overall system. This contractor, in turn, will let subcontracts for specific items of specialized equipment (i.e., belting, etc.). A list of the individual elements associated with a belt conveyor system include the following:

- Belting
- Conveyor Structure
- Transfer Components (head frames, transfer hoppers, transfer houses)
- Idlers

- Terminal Equipment (pulleys, motors, controls, and reducers; erected and wired)
- Power Line
- Transformers
- Concrete Footers
- Access Road
- Underpasses
- Barbed Wire Fence

Loading and Unloading Facilities

The loading facility for the movement of dredged material in a relatively dry state is much the same as that planned for truck haul with two exceptions (refer to the Truck Loading Facility description in Part VII). The first is that only a single feedout bin is required to load the long distance belt conveyor, and the second is that the excavation operation and feedout belt conveyor links are reduced in scale to sustain a continuous operation but of a much lower hourly capacity than required for either rail or truck hauling. The reason for the latter change is that belt conveyors are capable of transporting very large annual quantities of material (i.e., up to 20 million cubic yards per year), and in order to realize economies of usage they must be operated near full utilization (i.e., 280 days per year, 24 hours per day). Full yearly utilization, in turn, requires that the daily operational throughput must be reduced to sustain a full 280 day yearly utilization rate. For the low annual volume movements (e.g., 500,000 cu yd/yr) the scaled down loading operation will involve the use of smaller backhoe diggers and lower capacity feeder belt conveyors within the existing disposal area.

The unloading facility at the distant inland disposal area will involve the use of a movable radial belt stacker to feed large stockpiles for subsequent dispersal in the disposal area, or for subsequent productive uses.

Both the loading and unloading facilities will be rated for daily throughput to be equal to that of the long-distance belt conveyor system.

Related Applications

There are a number of high volume bulk material movement applications which are related to the transport of dredged material by long-distance belt conveyors. Selected applications are briefly described to provide examples of belt conveyor usage.

Perhaps the most interesting application is the 62-mile belt conveyor system which currently is operational in the Spanish Sahara.[51] This system hauls phosphate from the Bu-Craa mine to the port of El Aaiun. The 62-mile system is divided into eleven flights ranging in length from 4.2 miles to 7.3 miles. The handling rate is 2000 tons per hour and the belt width is 40 inches. The dip in altitude between the mine and port is 213 meters. The belt speed is 10 miles per hour, and haulage time from the mine to the port is 6 hours. Annual volume movement is 10,000,000 tons per year. Fifty-one drive units are used with an approximate horsepower rating 500 hp per drive unit. The conveyor framework is provided with a roof and side walls. Frame supports are spaced at 6-meter intervals and anchored in concrete sleepers. Krupp International, Inc. was the designer and builder of this belt conveyor system for the Spanish Government Mining Company.

A second application is the 5-mile belt conveyor system owned by the Peabody Coal Company that transports coal from its Eagle Mine to a stockpile barge loading facility near Old Shawneetown.[52] The belt conveyor system has ten flights ranging in length from 1,406 to 3,900 feet. The belt width is 42 inches and eighteen 100-hp drive motors are utilized. Belt structures are supported on concrete footers buried below the frost line at 20-foot intervals. The troughing angle is 35° and rated capacity is 1000 tons per hour. Barber-Green Company was the overall contractor for the belt conveyor system.

For the construction of Canada's Portage Mountain Dam, a 15,000-foot long belt conveyor was used to move nearly 60 million yards of material to make an embankment for the dam.[53] The belt conveyor crossed rugged terrain where trucks or scrapers would have had difficulty especially during the winter months. The belt width was 66 inches with a capability of 12,000 tons per hour at 1100 feet per minute. The belt troughing angle was 35° and four 840-hp electric motors were utilized. Construction of the dam was performed by a joint venture between Peter Kiavit Sons Co. of Canada Ltd., of Vancouver, Dawson Construction Ltd., of Vancouver, and Al Johnson Construction Company of Minneapolis.

Other long-distance belt conveyor systems are listed below:

- 35-mile system for transporting manganese to the Bay of Caldere in Chile is in the planning stage.[54]
- 50- to 140-mile system for transporting iron ore in India is in the planning stage.[54]
- 930-foot conveyor system over the Snake River in Washington to carry fill to the Ice Harbor Dam.[55]
- Orville Dam project utilized 7,200-foot, 54-inch wide belt conveyor system with a flow of up to 5,700 tons per hour.[55]
- 4.5-mile conveyor system to haul raw coal from mine to preparation plant utilized six flights, 36-inch belt, at a rated capacity of 800 tons per hour.[56]
- At a Kentucky coal mining operation, a 36-inch wide belt conveyor transports 400 tons of coal per hour from the coal preparation plant at the mine, crossing the Cumberland River on a cable suspension bridge of about 870-foot span, to deliver its load direct to a power plant.[57]

Cost Analysis

Belt Conveyor Pricing

The transportation of bulk material by belt conveyor systems is not controlled by any pricing regulations because long-distance movements have not involved crossing state lines. The basis for cost

derivations associated with belt conveyor systems must be made from cost data provided on existing systems and projected estimates by belt conveyor contractors.

Belt Conveyor Cost Assumptions

The primary assumption which is made herein in relation to costing of belt conveyors is that right-of-way for the system is available at no cost to the Government. This assumption is made to ensure consistency in cost comparisons between pipeline, rail, truck and barge transportation modes where no cost is associated with acquisition of, or improvements to, routes to be traveled.

A second assumption for costing purposes is that the route over which the belt conveyor system will traverse does not include spanning large water areas or travel across mountainous areas. If unusual terrain is encountered, increased costs will undoubtedly occur.

The final assumption is that the projected economic life of the belt conveyor system is twenty years to ensure consistency with the costing of the other transportation modes. Although this time span substantially exceeds the usual economic life for belt conveyor systems, two considerations have been made to justify this assumption. The first is that the estimated investment cost utilized for belt conveyor systems has been selected on the high side to ensure that high quality components are utilized, and the second is that an extensive preventive maintenance schedule is anticipated to ensure that all components are properly serviced and/or replaced on a scheduled basis. It is believed that these two considerations will ensure a twenty-year economic life for the belt conveyor systems.

Cost Derivations - Loading and Unloading Facilities

The cost derivations for the belt conveyor loading facility and operations are provided in Tables 8-1 through 8-6. These tables contain both amortized fixed costs and operational costs for varying annual volume requirements. Table 8-7 presents in summary form the

Table 8-1

Fixed Cost Derivation - Belt Conveyor Loading Facility (500,000 and 1,000,000 Cubic Yards per Year)*

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc. Rate (%)	Annual Maintenance, Repair, Insurance, Security, Misc. Charge (% x Basic Cost)	Total Annual Cost
2 portable feeder bins for belt conveyor (5 cu yd ea @ $10,000 ea)	$20,000	$5,000	$25,000	20	$2,360	32	$6,400	$8,760
1 portable belt conveyor (30" belt, 200 cu yd/hr, 1250-ft length @ $200/ft)	250,000	62,500	312,500	20	29,497	27	67,500	96,997
1 fixed belt conveyor (30" belt, 200 cu yd/hr, 3500-ft length @ $200/ft)	700,000	175,000	875,000	20	82,592	18	126,000	208,592
1 feedout bin (100 cu yd ea @ $150,000 ea)	150,000	37,500	187,500	20	17,698	32	48,000	65,698
								$380,047
							Estimate	$380,000

*The variation in configuration between 500,000 and 1,000,000 cubic yards per year facilities will be small; therefore, annual cost estimates for these facilities are the same.

Table 8-2

Variable Cost Derivation - Belt Conveyor Loading Facility

(500,000 and 1,000,000 Cubic Yards Per Year) *

Item	Description	Annual Cost
Disposal area excavation	2 backhoe excavators, 24 hrs/day, 280 days/yr @ $40/hr ea**	$537,600
	2 backhoe operators, 24 hrs/day, 280 days/yr @ $12/hr***	161,280
Facility operations	4 men, 24 hrs/day, 280 days/yr @ $9/hr***	241,920
	1 bulldozer, 8 hrs/day, 280 days/yr @ $24/hr	53,760
	1 bulldozer operator, 8 hrs/day, 280 days/yr @ $12/hr***	26,880
Electric power	200 hp @ 24/hrs day, 280 days/yr @ $.0157/hp hour	21,101
		$1,042,541
	Estimate	$1,050,000

*The variable costs associated with operating the the 500,000 and 1,000,000 cubic yards per year loading facilities are estimated to be the same because a minimum work force level is required for full yearly operations regardless of the volume of throughput per year.

**Based upon utilization of smaller backhoe excavator.

***Contractor overhead and fee included @ 50%.

Table 8-3

Fixed Cost Derivation - Belt Conveyor Loading Facility
(3,000,000 Cubic Yards per Year)

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc.		Total Annual Cost
						Rate (%)	Charge (% x Basic Cost)	
2 portable feeder bins for belt conveyor (5 cu yd ea @ $10,000 ea)	$20,000	$5,000	$25,000	20	$2,360	32	$6,400	$8,760
1 portable belt conveyor (36" belt, 600 cu yd/hr, 1250-ft length @ $300/ft)	375,000	93,750	468,250	20	44,198	27	101,250	145,448
1 fixed belt conveyor (36" belt, 600 cu yd/hr, 3500-ft length @ $300/ft)	1,050,000	262,500	1,312,500	20	123,887	18	189,000	312,887
1 feedout bin (100 cu yd ea @ $150,000 ea)	150,000	37,500	187,500	20	17,698	32	48,000	65,698
								$532,793
							Estimate	$535,000

Table 8-4

Variable Cost Derivation - Belt Conveyor Loading Facility

(3,000,000 Cubic Yards Per Year)

Item	Description	Annual Cost
Disposal area excavation	2 backhoe excavators, 24 hrs/day, 280 days/yr @ $50/hr ea	$672,000
	2 Backhoe operators, 24 hrs/day, 280 days/yr @ $12/hr*	161,280
Facility operations	4 men, 24 hrs/day, 280 days/yr @ $9/hr**	241,920
	1 bulldozer, 8 hrs/day, 280 days/yr @ $24/hr	53,760
	1 bulldozer operator, 8 hrs/day, 280 days/yr @ $12/hr*	26,880
Electric power	300 hp @ 24 hrs/day, 280 days/yr @ $.0157/hp hour	31,652
		$1,187,492
	Estimate	$1,190,000

*Contractor overhead and fee included @ 50%.

**Based upon utilization of smaller backhoe excavator.

Table 8-5

Fixed Cost Derivation - Belt Conveyor Loading Facility
(5,000,000 Cubic Yards per Year)

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc. Rate (%)	Annual Maintenance, Repair, Insurance, Security, Misc. Charge (% x Basic Cost)	Total Annual Cost
2 portable feeder bins for belt conveyor (5 cu yd ea @ $10,000 ea)	$20,000	$5,000	$25,000	20	$2,360	32	$6,400	$8,760
1 portable belt conveyor (40" belt, 1000 cu yd/hr, 1250-ft length @ $400/ft)	500,000	125,000	625,000	20	58,994	27	135,000	193,994
1 fixed belt conveyor (40" belt, 1000 cu yd/hr, 3500-ft length @ $400/ft)	1,400,000	350,000	1,750,000	20	165,183	18	252,000	417,183
1 feedout bin (100 cu yd ea @ $150,000 ea)	150,000	37,500	187,500	20	17,698	32	48,000	65,698
								$685,635
							Estimate	$685,000

Table 8-6

Variable Cost Derivation - Belt Conveyor Loading Facility

(5,000,000 Cubic Yards Per Year)

Item	Description	Annual Cost
Disposal area excavation	2 backhoe excavators, 24 hrs/day, 280 days/yr @ $55/hr ea	$739,200
	2 backhoe operators, 24 hrs/day, 280 days/yr @ $12/hr*	161,280
Facility operations	4 men, 24 hrs/day, 280 days/yr @ $9/hr*	241,920
	1 bulldozer, 8 hrs/day, 280 days/yr @ $24/hr	53,760
	1 bulldozer operator, 8 hrs/day, 280 days/yr @ $12/hr*	26,880
Electric power	400 hp @ 24 hrs/day, 280 days/yr @ $.0157/hp hour	42,202
		$1,265,242
	Estimate	$1,270,000

*Contractor overhead and fee included @ 50%.

Table 8-7

Summary of Belt Conveyor Loading Costs

	Annual Volume (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
Utilization percent	100	100	100	100
Fixed yearly cost ($000)	380	380	535	685
Variable yearly cost ($000)	1,050	1,050	1,190	1,270
Total yearly cost ($000)	1,430	1,430	1,725	1,955
Dollars/cubic yard	2.86	1.43	0.58	0.39
Allocated cost per mile (cents per cubic yard per mile)				
@ 6 miles	47.70	23.80	9.67	6.50
@ 10 miles	28.60	14.30	5.80	3.90
@ 20 miles	14.30	7.15	2.90	1.95
@ 40 miles	7.15	3.58	1.45	.98
@ 60 miles	4.77	2.38	.97	.65

total costs and unit costs (¢/cu yd/mi) for the belt conveyor loading operation. It can be seen from this table that relatively higher loading costs will be experienced for both low annual volume movements and short distance movements, and substantial economies can be realized from higher volume movements and longer distance movements.

Tables 8-8 and 8-9 present the cost derivations for the belt conveyor unloading facility and operations. Both the fixed costs and variable costs for varying annual quantities are provided in these tables. Table 8-10 presents a summary of these costs as well as allocated unit costs on a cents per cubic yard per mile basis.

Cost Derivations - Long-Distance Belt Conveyor System

Table 8-11 provides the cost derivation for the fixed costs associated with a single, 2-mile belt conveyor system flight. These data are based upon estimates provided by belt conveyor system manufacturers. The "basic cost" represents a total package cost for purchase and installation of a complete system. It should be noted that the variations in cost between the 500,000 and 1,000,000 cu yd systems are based upon greater throughput which results from increased speed of the belt and is obtained by increasing the drive horsepower. Additionally, system components must be designed to handle the increased belt speed. Table 8-12 provides the corresponding cost derivation for the variable operation costs associated with a single belt conveyor system flight. Table 8-13 presents a summary of Tables 8-11 and 8-12 for 6, 10, 20, 40, and 60-mile length belt conveyor systems on a unit cost basis (¢/cu yd/mi).

Total Combined Belt Conveyor System Unit Costs

Table 8-14 and Figures 8-1 and 8-2 provide a summary of the total combined costs associated with the transportation of dredged material for varying annual volumes and varying distances. It can be seen from this table that at the low annual volume level (i.e., 500,000 cu yd) and short distance movement (i.e., 6 miles), both handling and transportation unit costs are relatively high and nearly equal in contribution to the

Table 8-8

Fixed Cost Derivation - Belt Conveyor System Unloading Facility

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc.		Total Annual Cost
						Rate (%)	Charge (% x Basic Cost)	
500,000 and 1,000,000 Cubic Yards Annually*								
Radial belt stacker (30" belt, 200 cu yd/hr, 40-ft boom @ $300,000)	$300,000	$75,000	$375,000	20	$35,396	12	$36,000	$71,396
							Estimate	$71,000
3,000,000 Cubic Yards Annually								
Radial belt stacker (36" belt, 600 cu yd/hr, 40-ft boom @ $350,000)	350,000	87,500	437,500	20	41,296	12	42,000	$83,296
							Estimate	$83,000
5,000,000 Cubic Yards Annually								
Radial belt stacker (40" belt, 1000 cu yd/hr, 40-ft boom @ $400,000)	400,000	100,000	500,000	20	47,195	12	48,000	$95,195
							Estimate	$95,000

*Variation between 500,000 and 1,000,000 cubic yard cases will be only minimal.

Table 8-9

Variable Cost Derivation - Belt Conveyor System Unloading Facility

Item	Description	Annual Cost
	500,000 and 1,000,000 Cubic Yards Annually*	
Operations	2 men, 24 hrs/day, 280 days/yr @ $9/hr**	$120,960
Power	150 hp, 24 hrs/day, 280 days/yr @ $.0157/hp hour	15,826
		$136,786
	Estimate	$137,000
	3,000,000 Cubic Yards Annually	
Operations	2 men, 24 hrs/day, 280 days/yr @ $9/hr**	$120,960
Power	300 hp, 24 hrs/day, 280 days/yr @ $.0157/hp hour	31,652
		$152,612
	Estimate	$153,000
	5,000,000 Cubic Yards Annually	
Operations	2 men, 24 hrs/day, 280 days/yr @ $9/hr**	$120,960
Power	400 hp, 24 hrs/day, 280 days/yr @ $.0157/hp hour	42,202
		$163,162
	Estimate	$163,000

*Variation between 500,000 and 1,000,000 cubic yard cases will be minimal.

**Contractor overhead and fee included @ 50%.

Table 8-10

Summary of Belt Conveyor Unloading Costs

	Annual Volume (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
Utilization percent	100	100	100	100
Fixed yearly cost ($000)	71	71	83	95
Variable yearly cost ($000)	137	137	153	163
Total yearly cost ($000)	208	208	236	258
Dollars/cubic yard	0.42	0.21	0.08	0.05
Allocated cost per mile (cents per cubic yard per mile)				
@ 6 miles	6.93	3.47	1.31	.86
@ 10 miles	4.16	2.08	.79	.52
@ 20 miles	2.08	1.04	.40	.26
@ 40 miles	1.04	.52	.20	.13
@ 60 miles	.69	.35	.13	.09

Table 8-11

Fixed Cost Derivation - Single Flight (2 Miles Long) Belt Conveyor System

Item	Basic Cost	Contingencies and Overhead @ 25%	Total First Cost	Economic Life (Years)	Annual Capital Charge @ 7%	Annual Maintenance, Repair, Insurance, Security, Misc.		Total Annual Cost
						Rate (%)	Charge (% x Basic Cost)	
500,000 Cubic Yards Annually								
30" belt system @ $150/ft	$1,584,000	$396,000	$1,980,000	20	$186,892	18	$285,120	$472,012
							Estimate	$475,000
1,000,000 Cubic Yards Annually								
30" belt system @ $200/ft	2,112,000	528,000	2,640,000	20	249,190	18	380,160	629,350
							Estimate	$630,000
3,000,000 Cubic Yards Annually								
36" belt system @ $250/ft	2,640,000	660,000	3,300,000	20	311,487	18	475,200	786,687
							Estimate	$790,000
5,000,000 Cubic Yards Annually								
40" belt system @ $350/ft	3,696,000	924,000	4,620,000	20	436,082	18	665,280	1,101,362
							Estimate	$1,100,000

Table 8-12

Variable Cost Derivation - Single Flight (2 Miles Long) Belt Conveyor System

Item	Description		Annual Cost
	500,000 Cubic Yards Annually		
Facility operation	1 man, 8 hrs/day, 280 days/yr @ \$9/hr*		\$20,160
Electric power	150 hp @ 24 hrs/day, 280 days/yr @ \$.0157/hp hour		15,826
			\$35,986
		Estimate	\$36,000
	1,000,000 Cubic Yards Annually		
Facility operation	1 man, 8 hrs/day, 280 days/yr @ \$9/hr*		\$20,160
Electric power	200 hp @ 24 hrs/day, 280 days/yr @ \$.0157/hp hour		21,101
			\$41,261
		Estimate	\$41,000
	3,000,000 Cubic Yards Annually		
Facility operation	1 man, 8 hrs/day, 280 days/yr @ \$9/hr*		\$20,160
Electric power	300 hp @ 24 hrs/day, 280 days/yr @ \$.0157/hp hour		31,652
			\$51,812
		Estimate	\$52,000
	5,000,000 Cubic Yards Annually		
Facility operation	1 man, 8 hrs/day, 280 days/yr @ \$9/hr*		\$20,160
Electric power	400 hp @ 24 hrs/day, 280 days/yr @ \$.0157/hp hour		42,202
			\$62,362
		Estimate	\$62,000

*Contractor overhead and fee included @ 50%.

Table 8-13

Summary Annual Costs - Belt Conveyor System (Transportation Only)

Unit Costs	Annual Volume (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
6 Miles (3 Flights)				
Total cost ($000)	1,533	2,013	2,526	3,486
Dollars/cubic yard	3.07	2.01	0.84	0.70
Cents/cubic yard/mile	51.1	33.6	14.0	11.6
10 Miles (5 Flights)				
Total cost ($000)	2,555	3,355	4,210	5,810
Dollars/cubic yard	5.11	3.36	1.40	1.16
Cents/cubic yard/mile	51.1	33.6	14.0	11.6
20 Miles (10 Flights)				
Total cost ($000)	5,110	6,710	8,420	11,620
Dollars/cubic yard	10.22	6.71	2.81	2.32
Cents/cubic yard/mile	51.1	33.6	14.0	11.6
40 Miles (20 Flights)				
Total cost ($000)	10,220	13,420	16,840	23,240
Dollars/cubic yard	20.44	13.42	5.61	4.65
Cents/cubic yard/mile	51.1	33.6	14.0	11.6
60 Miles (30 Flights)				
Total cost ($000)	15,330	20,130	25,260	34,860
Dollars/cubic yard	30.66	20.13	8.42	6.97
Cents/cubic yard/mile	51.1	33.6	14.0	11.6

Table 8-14

Total Combined Unit Costs - Belt Conveyor Systems

Cost (Cents per Cubic Yard per Mile)	Annual Volume (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
6 Miles				
Loading/unloading	54.60	27.30	10.98	7.36
Transportation	51.10	33.60	14.00	11.60
Total	105.70	60.90	24.98	18.96
(Dollars/cubic yards)	($6.34)	($3.65)	($1.50)	($1.14)
10 Miles				
Loading/unloading	32.80	16.40	6.59	4.42
Transportation	51.10	33.60	14.00	11.60
Total	83.90	50.00	20.59	16.02
(Dollars/cubic yards)	($8.39)	($5.00)	($2.06)	($1.60)
20 Miles				
Loading/unloading	16.40	8.20	3.30	2.21
Transportation	51.10	33.60	14.00	11.60
Total	67.50	41.80	17.30	13.81
(Dollars/cubic yards)	($13.50)	($8.36)	($3.46)	($2.76)
40 Miles				
Loading/unloading	8.19	4.10	1.65	1.11
Transportation	51.10	33.60	14.00	11.60
Total	59.29	37.70	15.65	12.71
(Dollars/cubic yards)	($23.72)	($15.08)	($6.26)	($5.08)
60 Miles				
Loading/unloading	5.46	2.73	1.10	.74
Transportation	51.10	33.60	14.00	11.60
Total	56.56	36.33	15.10	12.34
(Dollars/cubic yards)	($33.94)	($21.80)	($ 9.06)	($7.40)

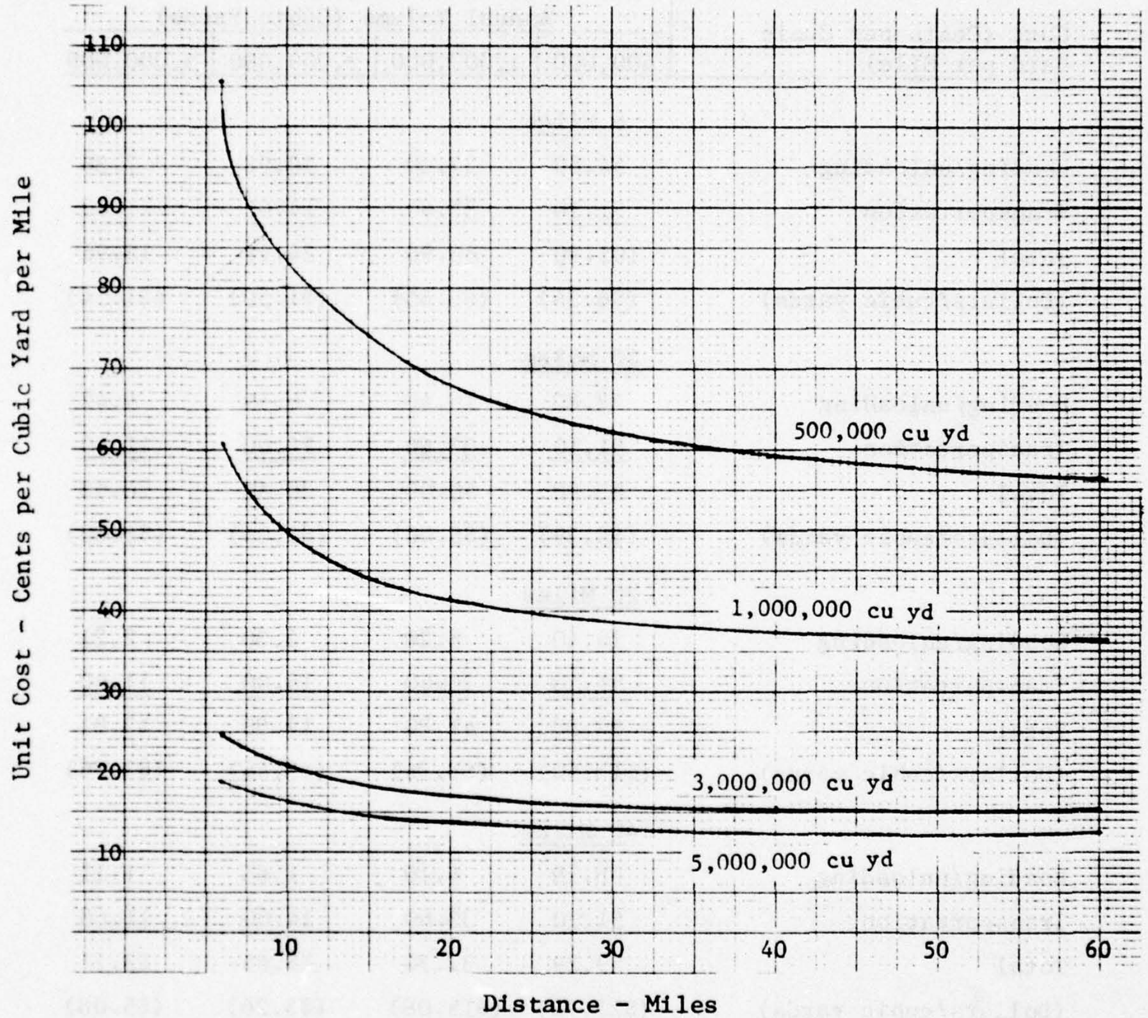

Figure 8-1. Total Belt Conveyor Unit Costs for Varying Annual Quantities

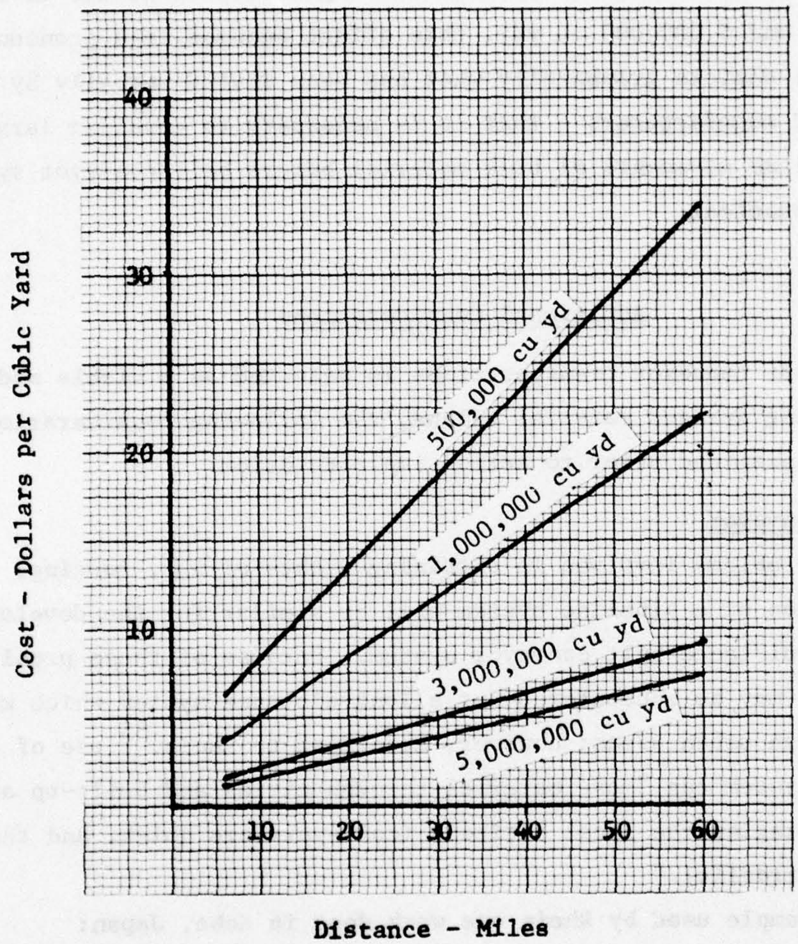

Figure 8-2. Total Belt Conveyor Costs (Dollars per Cubic Yard) for Varying Annual Quantities

total cost. At the longer distance movements (i.e., 60 miles) the transportation costs become the dominant factor.

From Figure 8-1 it can be seen that the annual volume of material being moved has a very significant effect on the unit cost of transporting dredged material. Between the higher volume levels (i.e., 3,000,000 and 5,000,000 cu yd), this effect becomes less pronounced. Figure 8-1 depicts graphically what has been stated verbally by conveyor belt manufacturers - that it is necessary to consider large annual volume movements of bulk material before belt conveyor systems become economical.

Additional Considerations

If belt conveyor transportation is selected as a viable mode for transporting dredged material inland, the following considerations should be examined prior to actual implementation.

Routing Conveyor

The problems involved in obtaining rights-of-way, routing, and construction of a pipeline system will be similar for the development of a long-distance belt conveyor system. Because of these problems, difficulty may be encountered for a long-distance system which must pass through urban areas; however, according to Rhein,[55] use of a conveyor system can "move material through cities and built-up areas without enraging the local citizens (conveyors are quiet, and they do not block traffic)."

An example used by Rhein was work done in Kobe, Japan:

> Operating near or through towns and built-up areas was one of the prime considerations.... At the seaport expansion of Kobe, Japan -- one of the world's densest population areas...there is scarcely any other choice except conveyors. Of the two conveyor systems used, one is underground and the other is covered along its entire length to lower the noise level and prevent dust from blowing about.[55]

Equipment Problems

A second difficulty which must be considered with a conveyor system is the problem of material pile-up. Since belt conveyor systems are comprised of segments, if one segment fails to operate, all other segments must be stopped to avoid pile-up of material and damage to equipment. Accidents may occur any place along the system, resulting in extensive damage unless there are controls to stop the conveyors.

> A fully loaded belt will coast on downgrade, sometimes to the extent that the drive motor becomes a generator and returns power to the circuit instead of consuming power. The reverse condition prevails on upgrades where a fully loaded belt will reverse travel following power cutoff. Obviously uncontrolled coasting on reverse travel of belt flights following power cutoff will result in...pile-up at transfer points.[58]

There are automatically controlled speed systems for this problem of pile-up of material. Other similar problems are:

> A common difficulty in belt transportation is clogging of chutes leading from one flight to another. This condition frequently results from oversize pieces lodging in the chute so passage of smaller material is blocked.[58]

> Steel objects that may pierce belting at a transfer point can cause extensive damage unless the belt is stopped immediately.... Where several panel belts discharge to a "mother" belt, full load discharge by each panel belt may develop a serious overloading problem on the mother belt.[58]

All of these considerations in use of belt conveyor systems mean that the system is:

> ...subject to the disadvantage that a major mechanical breakdown could be catastrophic, if the system is being relied upon as the principal means of material transportation.[59]

This possibility of mechanical breakdown can be minimized with a planned inspection and preventive maintenance program.

Weather Conditions

There is a difference of opinion as to the extent to which weather conditions adversely affect belt conveyor systems:

> Surface belt conveyors are usually subject to seasonal temperatures which, in cold weather, may chill the lubricants on all bearings and make start up extremely difficult. At one recent overland installation each flight was equipped with auxiliary slow speed drive that would operate the light belt at 50 fpm. It can be used to keep the machinery parts in slow motion during normal shutdown periods in cold weather so as to make start up easier....[60]

> Surface conveyors usually are provided with covers, frequently semicircular in shape, for protection against the weather.[60]

> Conveyors, unlike other haulers, can operate under almost all weather conditions. Despite snow or ice, conveyors will flow uninterrupted as easily as in fair weather. Like anything mechanical, however, they will rust, clog-up with snow or ice, and wear out faster in severe weather conditions. In extremely low temperatures, the rubber belt can break more easily.[55]

PART IX: COMPARATIVE ANALYSIS OF TRANSPORTATION SYSTEMS

General

Pipeline slurry, rail haul, barge movement, truck haul, and belt conveyor transportation alternatives have been individually analyzed on the basis of technical and economic considerations for the transportation of large quantities of dredged material over relatively long distances. Annual quantity movements have been varied from 500,000 to 5,000,000 cubic yards, and distances varied from six to 325 miles.

Comparison between these individual transportation modes or combinations thereof can be made both on technical and economic bases. However, it must be acknowledged that each particular application under consideration will be unique in one or more aspects; therefore, the transportation alternatives for each application must be evaluated based upon the merits and problems associated with that application.

Technical Considerations

The first and most important technical consideration is the nature of the dredged material to be transported. Only one of the transportation alternatives has been analyzed to move dredged material in a slurry state. That alternative involves hydraulic pipeline movement of the material. The other four basic transportation alternatives are based upon the movement of dredged material in a relatively dry state. Although these latter transportation alternatives can be utilized for transporting a slurry mixture, the costs associated with transporting a slurry mixture and the resulting attendant problems will be much higher than those of transporting relatively dry material.

For the movement of a slurried material by hydraulic pipeline transport, three methods were considered: centrifugal pumping, positive displacement pumping, and Pneuma pumping. Early in the analysis, positive displacement pumping was ruled out because of the nature of the material to be transported. Positive displacement pumps are very sensitive to the grain size of the solids in the slurry because this type of pump operates by means of a valve system through which the material passes. Consequently, they are subject to severe damage if slurries containing particles in excess of the maximum size limitations are introduced into the pumps. Since the nature of the dredged material is such that it could contain foreign matter and material of a size beyond the capability of the pump, extensive grinding and screening of the material would be required. The consideration of transport systems requiring extensive processing of the material is outside the scope of this study. Therefore, the use of positive displacement pumps was ruled out as a transportation alternative.

Thus, the hydraulic pumping analysis presented in Part IV examines two pumping alternatives: centrifugal pumping and Pneuma pumping. Centrifugal pumping of dredged material is a well-established method for transporting dredged material short distances (i.e., up to about ten miles); however, no attempt has been made to pump dredged material up to 100 miles using multiple booster stations. The only real limitations to such a long-distance system would be: (1) the requirement for a degree of redundancy in equipment at the booster stations to ensure continuing operations should one pump fail; (2) the suitability of the terrain and climate to permit pumping; and (3) the ability to dispose of the slurry effluent either at the distant disposal area or to return it back to its point of origin. In this regard, the analysis in Part IV addresses these limitations in the discussion of the technical design guidance for centrifugal pumping systems.

The Pneuma pumping system, also presented in Part IV is the second pipeline slurry alternative. Pneuma pumps use air pressure as the slurry's

prime mover. This pumping technique has been developed, perfected, and patented in Italy and is used in a number of pumping applications in Europe and elsewhere, as well as in specialized dredging applications. The technical advantage of Pneuma pumps is that much higher solids concentration can be achieved in comparison with centrifugal pumps. Also, because there are no moving parts in a Pneuma pump, it requires minimal maintenance. The technical limitations associated with pneumatic pumping systems are much the same as those associated with centrifugal pumping systems.

The technical considerations associated with the other four basic transportation modes (rail, barge, truck, belt conveyor) are for the most part straightforward in that a rail line, waterway, road and/or right-of-way must exist between the intermediate disposal area and the distant disposal area. Specific technical aspects associated with each of these modes are discussed in detail in the respective analytic sections of this report.

In summary, from a technical point of view, each of the five basic transportation modes can be selected to transport dredged material long distances inland. In some cases, limitations of a given transportation mode (i.e., presence of rail lines, waterways, etc.) will eliminate that particular mode from consideration. It is also quite possible that one or more combinations of these modes could be utilized to satisfy a given movement requirement. The following section points out that the transportation mode will have significant impact on the final economics of moving the material.

Economic Comparisons

Transportation costs will vary considerably depending upon the following major considerations:

- Annual volume of material being transported
- Density of the material (of particular significance in hydraulic pipeline transport)
- Distance

- Topography/climate
- Area of the country (i.e., labor rates, energy rates, etc.)
- Contractual arrangements

For this study, both the annual volume and distance variables have been examined within practical limits to permit analysis of their impacts on the costs of each transportation mode. In order to bound the scope of this study, general assumptions have been made regarding the other considerations.

Annual Volume Movements

Annual volume movements have been analyzed between 500,000 cubic yards and 5,000,000 cubic yards. For volumes under 500,000 cubic yards per year, the economies to be associated with large-scale movements will not be realized, and higher unit cost rates can be anticipated.

Density of the Material

This factor has a significant effect on costs for hydraulic pipeline transport (Pneuma and centrifugal). The greater the bulk density of the material in the disposal area the higher will be its cost for hydraulic transport. This results from the fact that for a given volume of in situ material, the corresponding volume of slurry mixture required to be pumped increases with an increase in the density of the in situ material. Its effects on the other modes of transport however is minor.

Distance

The distance which dredged material is to be moved inland has been varied between six and 325 miles. It should be noted that individual transportation modes have distance limits associated with practical operations; therefore, the costs associated with each transportation mode are presented within these limits. For example, belt conveyor and pipeline slurry (centrifugal and Penuma) systems would not be expected to be practical for distances in excess of 125 miles. Also, rail haul

would be utilized only in selected instances for short distance hauls (i.e., under 40 miles).

It is very important to note that, in comparing costs among alternative transportation modes for a given application, care must be taken to identify the actual distance associated with each alternative under consideration. Because of the nature of the right-of-way, rail lines, roads, and waterways, each transportation mode will have a different route (and associated distance) for the same overall point A to point B movement. Therefore, the user of the data presented on the following pages must avoid the potential pitfall for actual applications of comparing between transportation modes based upon the straight-line distance of A to B.

Topography/Climate

For purposes of this study, the topography between the intermediate and inland disposal areas is assumed to be relatively flat. That is, the economic impact of transporting dredged material over large elevations associated with mountain ranges, etc., has not been evaluated. If such topographical conditions exist, the costs associated with each transportation alternative will increase based upon the degree of difficulty of the terrain. Adverse weather conditions such as freezing weather and snow will, in some cases, also affect the costs presented herein. Where climate conditions require specialized equipment or result in reduced operations, costs can be expected to be higher than estimated herein.

Area of the Country

Cost data presented are based upon countrywide averages. For specific applications of these data, adjustments may be necessary for variations in local labor rates, power rates, etc.

Contractual Arrangements

In the majority of instances, for the movement of large volumes of dredged material on a continuing basis, a negotiated contract of some form will be associated with each transportation alternative. Inherent

in the process of contract negotiation is potential for price variations. Depending upon the degree to which competition is present, transportation rates can vary widely. Therefore, the rates presented in the following pages must be considered to be only averages. If substantial competition is present, transportation rates will most likely be lower; however, if competition is not present, these rates will undoubtedly be higher.

Other costing assumptions relating to each specific transportation mode are delineated in the respective sections of this report which address the transportation modes individually. These assumptions should be reviewed for each transportation alternative under consideration.

Cost Comparisons

Figures 9-1 through 9-4 present estimated unit costs in dollars per cubic yard for each of the five transportation modes (pipeline slurry, rail, truck, barge and belt conveyor) for varying annual quantity movements (500,000; 1,000,000; 3,000,000; and 5,000,000 cubic yards, respectively). The cost curves for hydraulic pipeline transport show the high and low cost limits as well as the "most probable" costs as developed in the sensitivity analysis of Part IV. For purposes of comparative analysis of transport modes, the cost values represented by the "most probable" curve are used. It should be recognized that in an actual application the conditions peculiar to a specific site will define the actual costs that will be incurred.

Overall, it can be seen from these graphs that irrespective of the annual volume movements, the belt conveyor and truck haul systems are considerably more expensive than pipeline, rail, or barge transportation systems. At the 500,000 cubic yard annual volume movement level, hydraulic pipeline transport is the most economical mode for distances up to about 20 miles. Beyond this distance and up to the limiting distance of this study, movement by barge is the most economical transport system. Movement by hydraulic pipeline is more economical than movement by rail up to a distance of about 60 miles. Beyond this point rail movement becomes

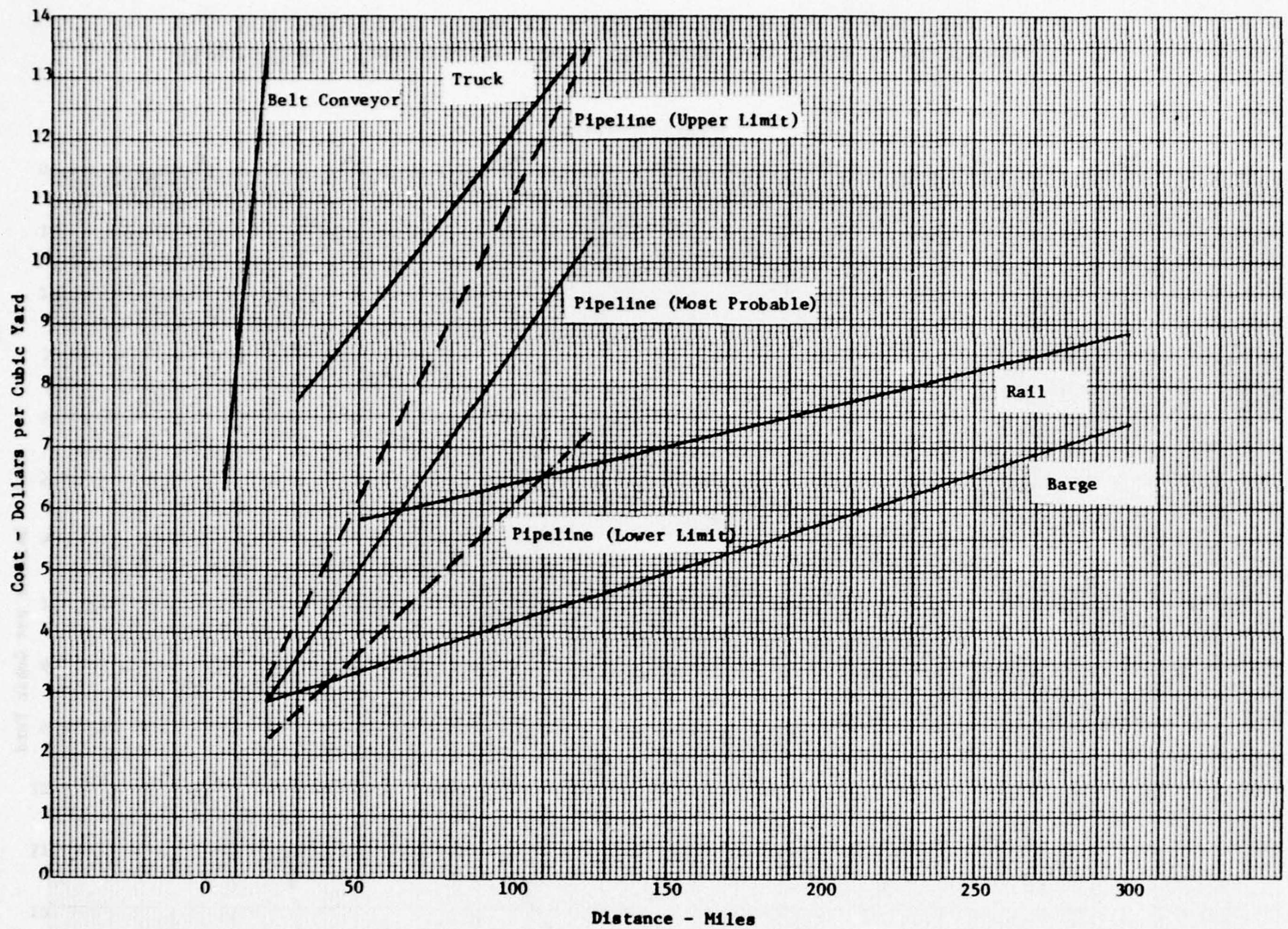

Figure 9-1. Comparative Costs (Dollars per Cubic Yard) Among Transportation Modes at 500,000 Cubic Yards per Year

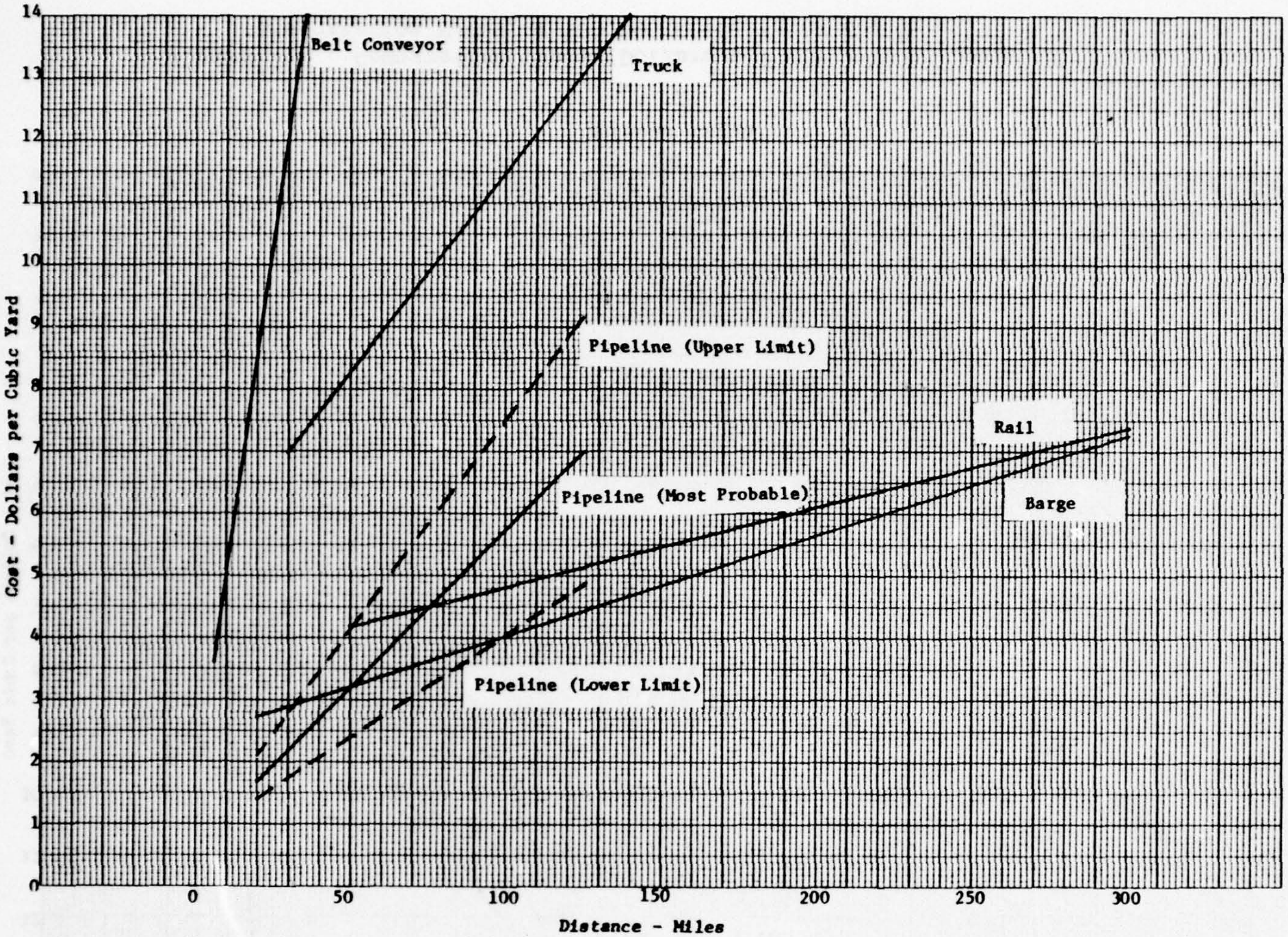

Figure 9-2. Comparative Costs (Dollars per Cubic Yard) Among Transportation Modes at 1,000,000 Cubic Yards per Year

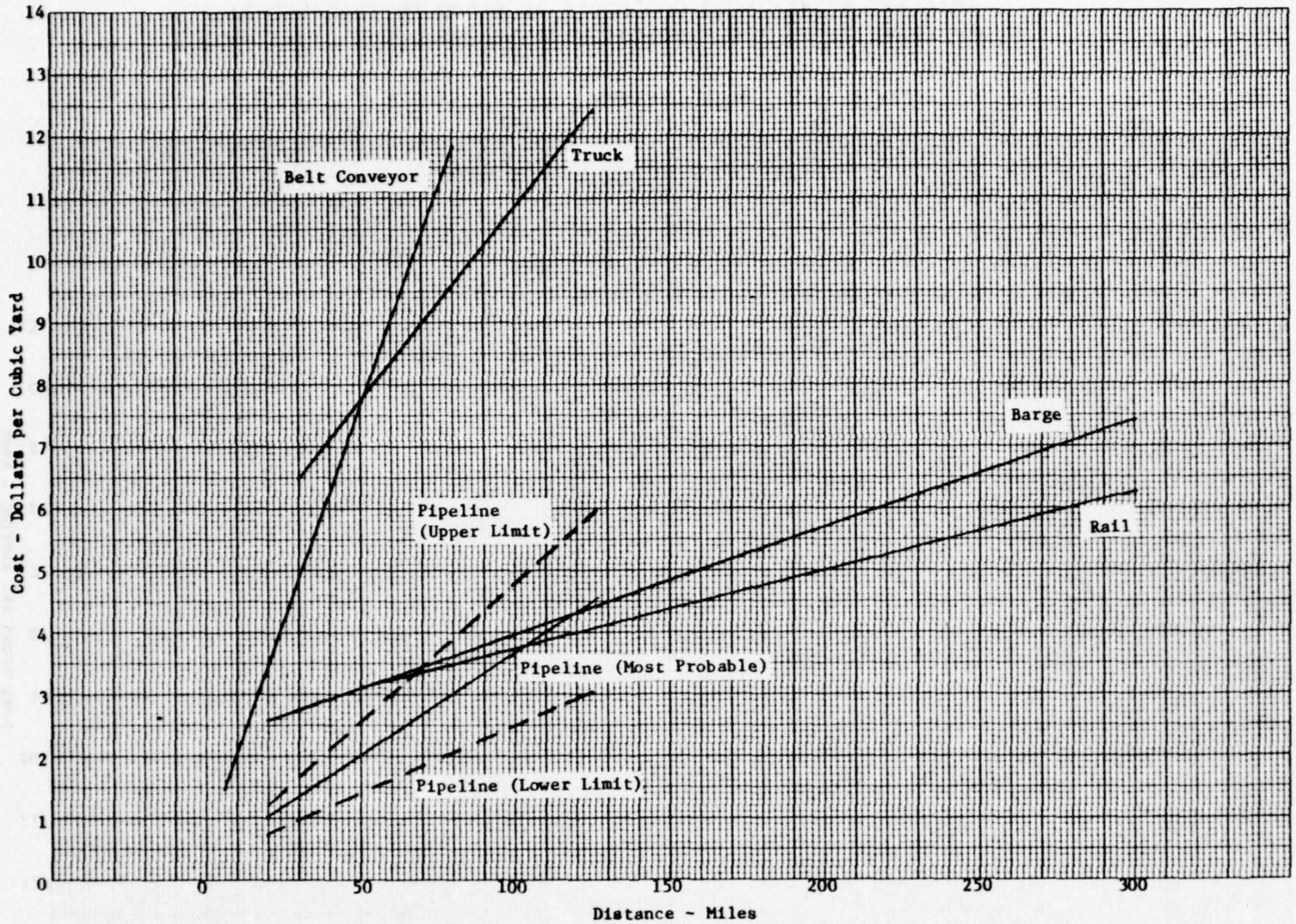

Figure 9-3. Comparative Costs (Dollars per Cubic Yard) Among Transportation Modes at 3,000,000 Cubic Yards per Year

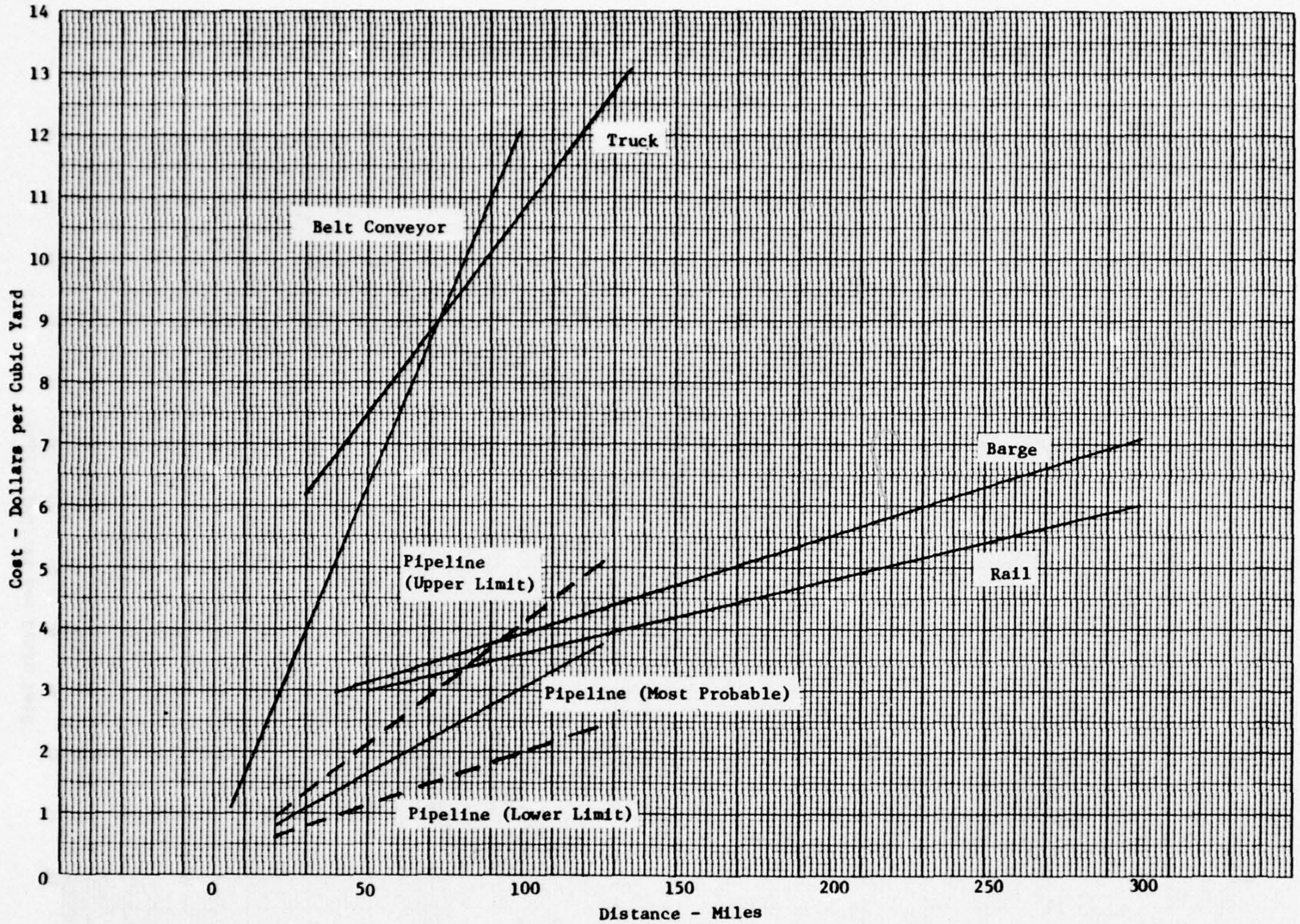

Figure 9-4. Comparative Costs (Dollars per Cubic Yard) Among Transportation Modes at 5,000,000 Cubic Yards per Year

less costly than pipeline movement. Therefore, for those applications where barge haul is not flexible (lack of suitable waterway to support barge to transport), the tradeoff point between hydraulic pipeline transport and rail transport is at the 60-mile distance.

When this annual volume movement level is increased to 1,000,000 cubic yards, the distance to which hydraulic pipeline transport is the most economical, increased from 20 to 50 miles. Barge haul is still the most economical beyond that point; however, where barge haul is not feasible the tradeoff point between rail and hydraulic is at the 75-mile distance.

At the 3,000,000 cubic yard annual movement level, hydraulic pipeline transport is the most economical up to a distance of about 115 miles. Up to and beyond this point, rail movement is now more economical than barge haul. As the annual volume movement increases above this level, there are no significant changes in the above cost pattern, except that hydraulic pipeline transport is the most economical up to its 125 miles practical limitation.

Figures 9-5 through 9-8 depict unit costs in dollars per cubic yard per mile for the same volume increments and distances as presented in Figures 9-1 through 9-4, respectively. The same economic characteristics discussed above are observed for these graphs with the exception that the asymptotic nature of these curves depicts the leveling off characteristic of unit costs in dollars per cubic yard per unit for greater distance movements.

Review of Economic Results

Hydraulic Pipeline Transport. For annual volume movements of 500,000 cubic yards, total hydraulic pipeline transport costs (dollars per cubic yard) will vary from about \$2.75 per cubic yard at 20 miles to about \$10.00 per cubic yard at 120 miles. For annual volume movements of 5,000,000 cubic yards, total hydraulic pipeline transport costs will vary from about \$0.80 per cubic yard at 20 miles to about \$3.60 per cubic

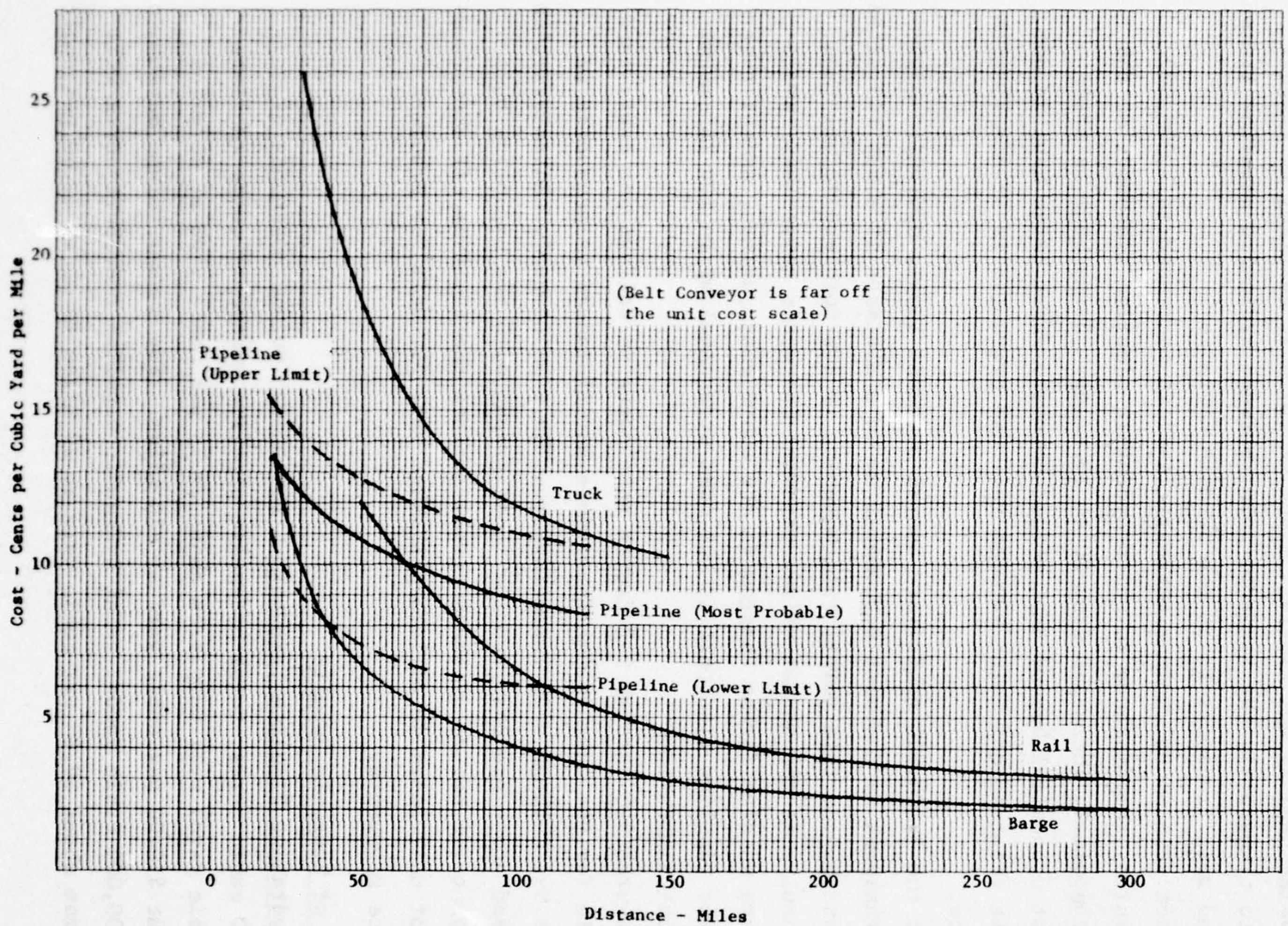

Figure 9-5. Comparative Costs (Dollars per Cubic Yard per Mile) Among Transportation Modes at 500,000 Cubic Yards per Year

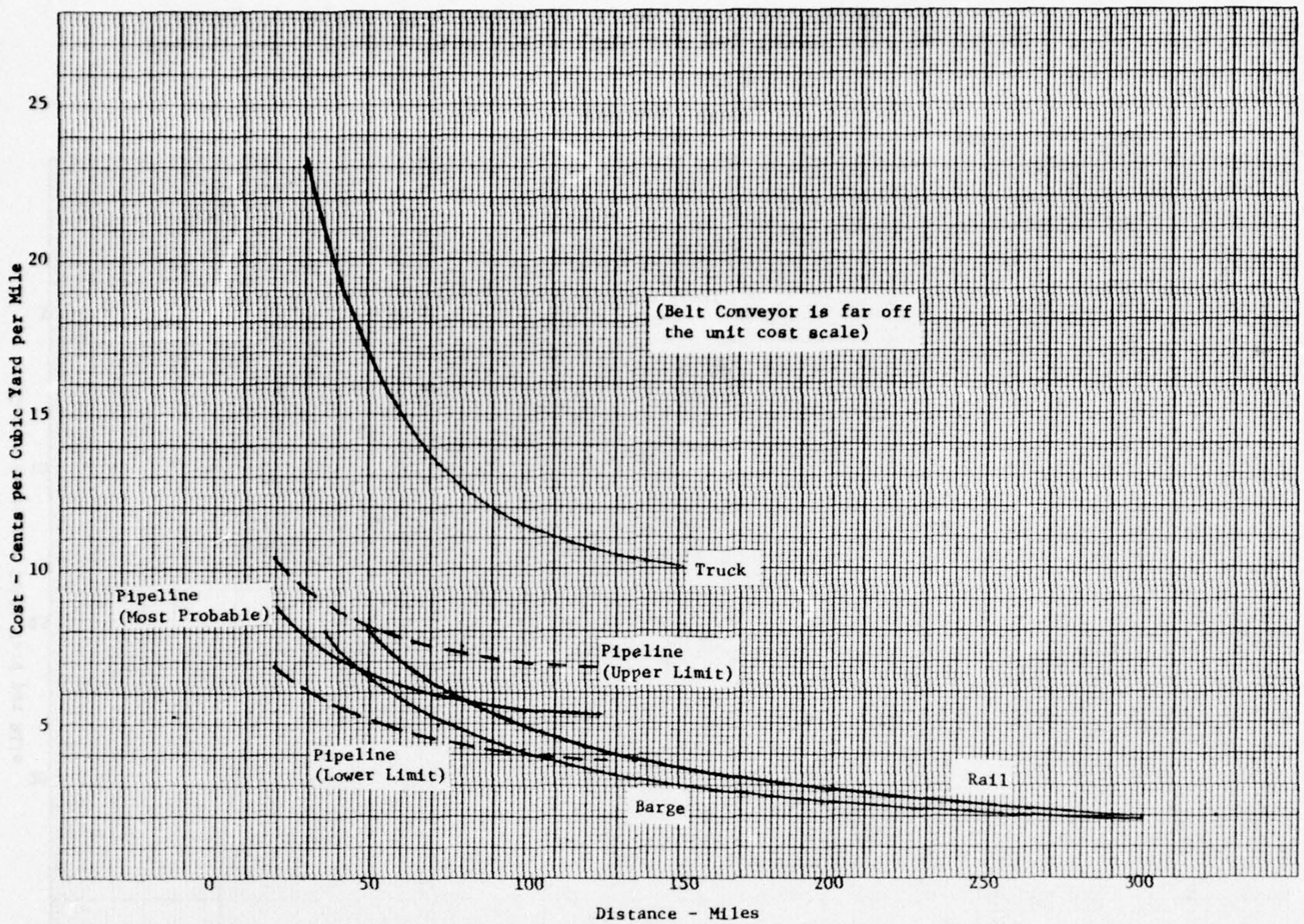

Figure 9-6. Comparative Costs (Dollars per Cubic Yard per Mile) Among Transportation Modes at 1,000,000 Cubic Yards per Year

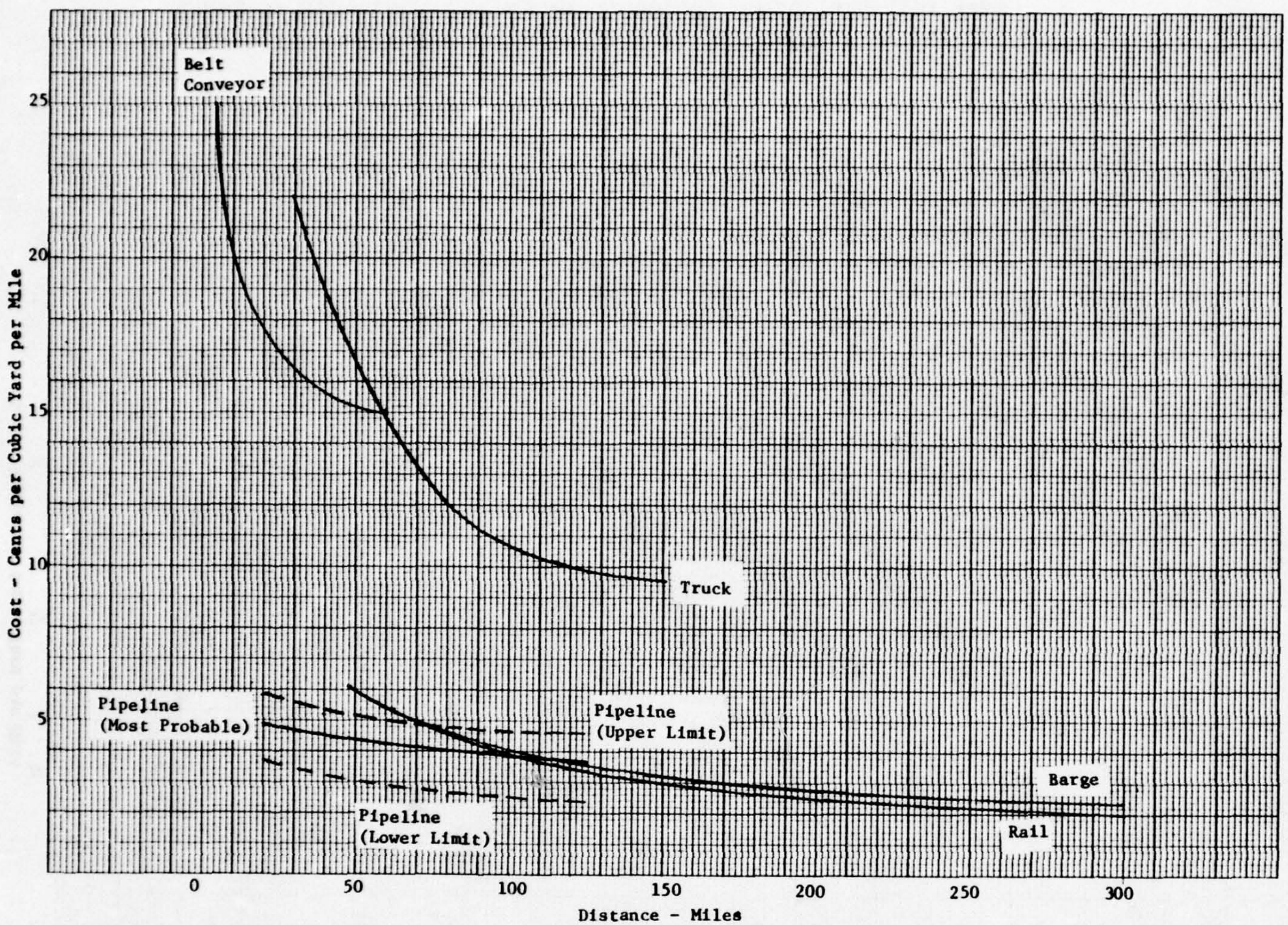

Figure 9-7. Comparative Costs (Dollars per Cubic Yard per Mile) Among Transportation Modes at 3,000,000 Cubic Yards per Year

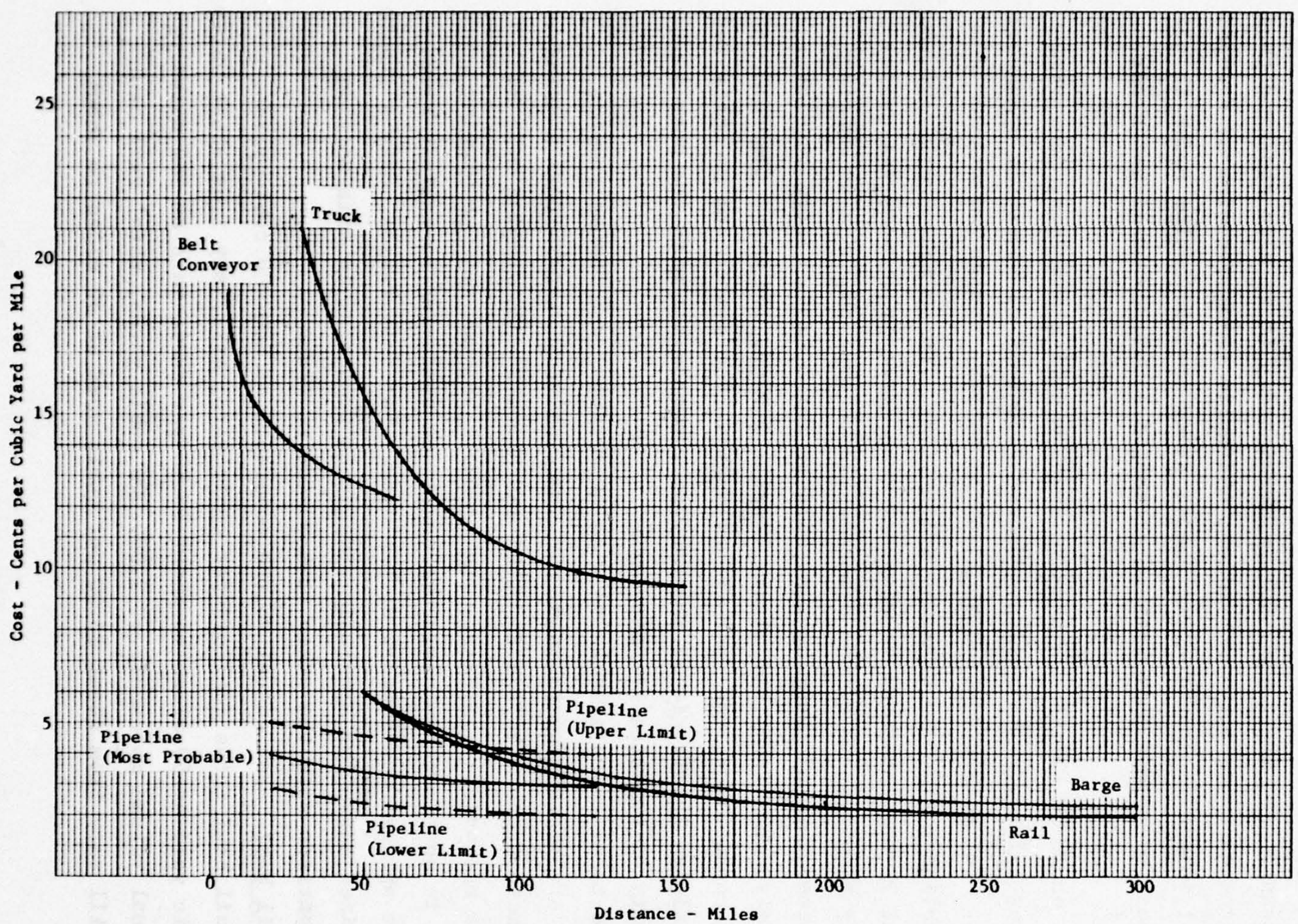

Figure 9-8. Comparative Costs (Dollars per Cubic Yard per Mile) Among Transportation Modes at 5,000,000 Cubic Yards per Year

yard at 120 miles. From these data it is apparent that for hydraulic transport of dredged material, unit costs (dollars/cubic yard) will drop significantly for the larger volume movements. It is also observed that for distances under about 50 miles, hydraulic transportation of dredged material inland is the economic choice among transportation modes in all instances for volume movements in excess of 1,000,000 cubic yards per year.

As shown in Part IV, Hydraulic Transportation Analysis, many variables can influence the design and resultant cost of hydraulic transport systems. For each projected application system, design parameters must be established prior to economic evaluation. The in situ density of the material in the intermediate disposal area directly affects the design capacity requirements of the systems. The higher the in situ density, the greater the unit pumping cost will be for a given slurry density. Conversely, the higher the slurry density pumped, the lower the unit pumping cost. Thus, the cost effectiveness of a system can be optimized if the slurry density is at the maximum commensurate with the pump's capability of handling the material.

The total costs associated with centrifugal and Pneuma pumping systems are closely comparable. In some instances centrifugal pumping is the more economical and in other instances Pneuma pumping will be the more economical. However, the tradeoff between the two pumping systems is so close that each one should be evaluated separately based upon the unique requirements of the case. For this reason, only a single generalized curve for hydraulic pumping is presented in this section for comparison with the other transportation modes.

Rail Haul. For annual volume movements of 500,000 cubic yards, total rail haul rates (dollars per cubic yard) will vary from about \$5.80 per cubic yard at 50 miles to about \$8.90 per cubic yard at 300 miles. For annual volume movements of 5,000,000 cubic yards, total rail haul rates will vary from about \$3.00 per cubic yard at 50 miles to about

$6.10 per cubic yard at 300 miles. The large reduction in total rail haul costs associated with larger volume movements can be attributed to reduced material handling unit costs (loading and unloading) and reduced transportation unit rates.

The break-even point between rail and barge haul for transporting dredged material inland occurs at annual volume levels of about 2,000,000 cubic yards. At higher annual volume levels, rail haul will be more economical; at lower annual volume levels, barge haul appears more economical (all other factors considered equal). In every case between 50 and 300 miles, rail haul appears to be more economical than either truck haul or belt conveyor movement.

It should be noted that care must be taken in extrapolating rail haul costs below 50-mile distances because no data on rail rates below 50 miles were utilized in this study. The availability of data for rail movements under 50 miles was very limited and fragmentary; therefore, no attempt has been made to derive total rail haul costs for short distance movements.

Barge Haul. For annual volume movements of 500,000 cubic yards, total barge haul rates (dollars per cubic yard) are estimated to be about $3.40 per cubic yard at 50 miles and about $7.40 per cubic yard at 300 miles. For annual volume movements of 5,000,000 cubic yards, total barge haul rates are estimated to be about $3.15 per cubic yard at 50 miles and about $7.20 per cubic yard at 300 miles. Since barging costs, both material handling and transportation elements, are considered to be closely related to volumes transported, only marginal cost reductions are observed in transporting larger annual volumes of material.

Overall, the results of the analysis indicate that for the lower annual volume movements, barge haul is one of the most economic means to transport dredged material inland. At the 500,000-cubic yard level, barging becomes the most economical option for distances in excess of 20 miles. At the 1,000,000-cubic yard level, the pipeline versus barging break-even point occurs at about the 50-mile point.

Truck Haul. For annual volume movements of 500,000 cubic yards, total truck haul costs will vary from about $7.75 per cubic yard at 30 miles to about $13.40 per cubic yard at 120 miles. For annual volume movements of 5,000,000 cubic yards, total truck haul costs will vary from about $6.20 per cubic yard at 30 miles to about $12.00 per cubic yard at 120 miles. Large-scale truck haul movements will yield reductions in unit costs; however, in comparison with other transportation alternatives, truck haul of dredged material is not closely competitive. In every case, where direct comparisons are valid, pipeline slurry, rail, and barge haul are more economical than the truck haul option. The underlying reason for these results can be many, but the most notable is that for the large annual volumes under consideration in this study, truck haul is a labor and fuel intensive mode of transportation in comparison with other transportation modes.

In comparison with belt conveyor movements, at the lower annual volumes truck haul is the more economical mode, while at higher annual volumes, belt conveyor systems are more economical up to distances of about 60 miles.

Belt Conveyor Movement. At the lower annual volumes, belt conveyor unit costs (dollars per cubic yard) are dramatically higher than any of the other competing transportation modes. However, at the higher annual cubic yard volume levels and over small distances (less than 20 miles), belt conveyor movement becomes competitive with all transportation alternatives except the pipeline slurry option. This result depicts the economic nature of belt conveyor transportation, which is its high investment cost but inherent ability to move extremely large annual quantities of bulk material.

Findings and Recommendations

Economic Preference

Based upon the technical considerations and cost derivation assumptions followed in this analysis, Table 9-1 presents a summary of the economic preferences for transporting dredged material inland for varying

Table 9-1

Summary of Economic Preferences

Distance	Annual Volume Movements (Cubic Yards)			
	500,000	1,000,000	3,000,000	5,000,000
10-50 Miles	1.* Barge 2. Pipeline 3. Truck 4. Belt Conveyor	1. Pipeline 2. Barge 3. Truck 4. Belt Conveyor	1. Pipeline 2. Barge 3. Belt Conveyor 4. Truck	1. Pipeline 2. Barge/Belt Conveyor 3. Truck
50-100 Miles	1. Barge 2. Rail 3. Pipeline 4. Truck	1. Barge 2. Pipeline/Rail 3. Truck	1. Pipeline 2. Rail/Barge 3. Truck	1. Pipeline 2. Rail 3. Barge 4. Truck
100-300 Miles	1. Barge 2. Rail	1. Barge 2. Rail	1. Rail 2. Barge	1. Rail 2. Barge

*Order of economic preference.

annual volumes over varying distances. It can be seen from this table that pipeline slurry transportation is the most economical choice in most instances for distances up to about 100 miles where annual quantities exceed 1,000,000 cubic yards. For longer distance movements, barge or rail haul will be the most economical selection depending upon the annual volumes to be transported. For these long-distance movements at low annual volumes, barge is the economical choice and for movements of higher volumes, rail is the more economical choice.

As discussed earlier, care must be taken in comparing cost data between transportation modes because each mode requires a specific transport route (rail line, waterway, etc.) which in the majority of instances will result in varying distance movements associated with each transportation mode for a given application. For example, a practical transportation application may involve the movement of dredged material from location A to location B where the direct line distance is 50 miles, the rail line distance 70 miles, the roadway distance 65 miles, and the water route 95 miles. For such a case the transportation costs, in terms of dollars per cubic yard, for each transportation mode must be compared based upon their respective distance movements.

Combining Transport Modes

It should also be noted that, as discussed in Part III of this report, in some cases combinations of transportation modes may be required to transport dredged material to an inland site. It is possible for a specific application that barge and truck haul, or barge and pipeline slurry modes, as well as other potential combinations, could be utilized. For economic evaluation of these cases, unit costs can be easily combined to evaluate the total transportation system's cost. However, care must be exercised to avoid double counting of the material handling activity at the point where the two transportation modes interface. For each transportation mode, the costs associated with material handling (i.e., loading and unloading) have been separately identified to facilitate

the combining of transportation modes. In these instances, at the point of interface between each transportation link, double counting will occur if both unloading and loading costs are included. Therefore, one of the two cost elements (unloading or loading) must be eliminated. For example, if barge haul is the first transportation mode and truck haul is the second, the operation of unloading barges directly into awaiting trucks is only a one-step process. If, however, the barge unloading process and the truck loading process are costed separately, double counting will occur. Given the form in which the cost data are derived in this report, it should be a straightforward process to avoid this potential double counting pitfall for those situations where multiple transportation links are required.

Practical Distance Limits

Unless unusual circumstances exist for a given application, the following practical distance limits are recommended for each transportation mode:

Hydraulic Pipeline Transport. It is recommended that the pipeline alternative be considered for distances up to about 125 miles. Distances in excess of 125 miles will increase the potential for system breakdown because of the increasing number of booster stations required.

Rail Haul. Rail haul should be considered for distance movements between 50 and 300 miles. At distances below 50 miles, available cost data are only fragmentary.

Barge Haul. Barge haul can be considered for all applications where suitable waterways exist.

Truck Haul. Truck haul should only be considered for distances up to about 50 miles. Movement of large quantities of dredged material in excess of 50 miles will be very uneconomical.

Belt Conveyor. Belt conveyor movement is best considered for those applications where very large volumes are required to be moved short distances. Practical distance limits for belt conveyor applications will be under 50 miles.

Summary

In summary, in selecting the most desirable transportation alternative, it is recommended the following sequence be followed.

Identify the available transportation routes and their respective distances for the movement of dredged material inland. In many cases a transportation alternative may be eliminated for lack of a suitable transportation route.

Identify the nature and characteristics of the material to be transported (i.e., wet or relatively dry state, in situ density).

Determine the annual volume of material to be transported and the anticipated duration (years) of the project.

Derive estimated yearly costs for each transportation alternative based upon the methodology presented in this report. If cost data which are presented herein are utilized, care should be taken to update these data as required for the application under consideration.

Evaluate comparative costs to determine the most economical transportation alternative.

Evaluate additional technical, legal, environmental, and institutional considerations for each mode to ensure the practicability of the application.

Select the desired transportation alternative.

The above generalized procedure coupled with the detailed design and cost derivation methodology contained in this report will serve as a guide in evaluating among transportation systems for the movement of dredged material inland.

The final recommendation is that several case studies involving the application of these engineering and economic data to the specific requirements of actual cases be conducted. The performance and documentation of selected case studies would be a valuable supplement to this report.

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Appendix A

DREDGED MATERIAL TRANSPORT STUDY: A REVIEW OF THE INTERFACE BETWEEN DREDGING OPERATIONS AND THE LONG DISTANCE TRANSPORT SYSTEMS

General

Since this study is concerned primarily with the transport of dredged material in large quantities over relatively long distances, there is a need to establish the relationship between the dredging system and the transport system. Although there may appear to be a distinct delineation between a dredging system and a transport system, it must be pointed out that inherent in what is commonly known as the dredging system is also a transport subsystem. As examples, in hydraulic cutterhead dredging operations, the transport system could be considered to be that element of the overall dredging system represented by the reach of pipeline extending from the discharge end of the dredge to the disposal area. In hopper dredge operations, the vessel itself is the transport mode, since the material confined in the hoppers is physically transported by the vessel (dredge) to the place of final or intermediate disposal. At that location the transported dredged material is either bottom dumped for final disposal (or rehandled by auxiliary equipment to an adjacent upland area), or if the hopper dredge is equipped with a pumpout capability, the material is pumped out hydraulically to an adjacent upland disposal area. In the case of a mechanical dredge operation (bucket, dipper, clamshell), the transport subsystem is the barge or scow that is loaded by the dredge with the excavated material and, similar to the transport phase of hopper dredge operations, the loaded scows or barges are transported to a disposal site where the material is either bottom dumped for final disposal or pumped out by auxiliary equipment to adjacent upland disposal areas. It should be noted that scows can also be loaded

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by a hydraulic pipeline dredge and when such is the case the dredge could be considered as operating in a manner similar to the mechanical dredges.

One of the problems facing the researcher in establishing the study's direction, bearing in mind its ultimate objective (concepts for long distance dredged material transport systems for inland disposal), is the determination of whether the dredging operation and its inherent transport system should be considered a subsystem in the overall transport system. To make such a determination, a review must be made of the purpose, need, and requirements for the dredging operation. One of the basic premises underlying this study is that it encompass only those dredging operations conducted by or for the Corps of Engineers. The dredging requirements of the Corps stem from its vested responsibility for improving and maintaining the Federal navigation projects. This is a great responsibility, since the viability of the nation's economy is clearly dependent upon the Corps' ability to keep the navigation channels open to maritime commerce primarily by means of dredging. The Corps' dredging operations must, therefore, be performed in a timely manner and on an efficient basis. Any undue delays in the dredging operation or use of inefficient or impractical operational procedures could affect the adequacy of channel depths in major waterways and, as a consequence, could disrupt the normal movement of waterborne traffic. Recognizing these fundamental considerations, attention must be directed to the dredging operation itself (maintenance of a navigation channel) and critical review made of the factors associated therewith to ascertain whether inclusion of the dredging phase in the overall long distance transport system concept would: generate unacceptable delays; require such modifications in procedures which could not be tolerated; result in such other major problems for which practicable solutions are not readily apparent.

To facilitate this review and assure that all pertinent factors are considered, analyses will be made for the three basic dredging systems, that is, hydraulic, hopper, mechanical.

Hydraulic Cutterhead Dredge Operation

As indicated previously, the basic hydraulic cutterhead dredging operation involves the excavation of bottom material from within the channel prism by means of a cutterhead at the suction end of a centrifugal pump, the intake of this excavated material in slurry form into the pump, and the pumping of the slurry through a pipeline that consists of floating pontoon and a submerged and shore pipeline to a disposal area. Pumping operations are theoretically continuous except for those interruptions necessary to provide for:

1. Movement of dredge from one dredging area to another.
2. Necessity to interrupt operations to add sections of floating line as work progresses from one shore line junction to another.
3. Shutdowns to permit clearing of pump of foreign matter (rocks, wire, chain, etc.).
4. Shutdowns to permit emergency repairs to plant and equipment including cutterhead changes.
5. Shutdowns occasioned by inclement weather conditions.
6. Shutdowns associated with placement of swinging line anchors.
7. Clearing of line for planned shutdowns to prevent plugging of material in line.
8. Miscellaneous shutdowns.

Each of the above factors contributes to the overall loss in effective pumping time of the dredge. Because these factors are directly related to job conditions, very little control can be exercised to eliminate or minimize these production losses. These loss factors are, therefore, the norm in a hydraulic dredging operation.

Generally, and wherever practicable, disposal areas are so located that pipeline distances are within the pumping capability of the power plant and pump equipment of the dredge. When this is not possible, longer pipelines with requirements for one or more auxiliary booster pumping stations result. There is a practicable limit, however, as to the number of booster pumping stations which should be considered in a direct pump from a navigation channel dredging job. Background experience shows that for this type of work (navigation channel dredging), generally two booster stations are about the maximum used, which in the case of the larger diameter dredges will provide for a distance of about 25,000 feet or 5 miles. Factors which influence the use of a limited number of booster stations in connection with navigation channel dredging operations are:

1. Inability to control or confine flow conditions in the pumping system during navigation channel dredging operations to within the narrow limits required for effective operation of a multiple booster pump system.

2. High initial cost of booster pumping equipment and pipeline and cost of installation and dismantling after each job. Unless the dredging project involves yardage of considerable magnitude, the distributed unit costs become exorbitant and unrealistic.

3. Compounding of ineffective dredging time because of mechanical failures and normal breakdowns and maintenance requirements in the booster systems.

4. Additional lost time necessary to clear lines to prevent plugging because of interruption factors associated with the basic dredging operation (at slurry velocity of 12 feet per second and 5 mile pipeline, flushing of line with water to prevent plugging required approximately 40 minutes).

With respect to item 1 above, the production of hydraulic pipeline dredges in navigation channel work is directly related to the density and flow velocity of the dredged mixture or slurry pumped. The

density of slurry and flow velocity are generally dependent upon the configuration and characteristics of the bottom material, the depth of cut required to obtain specified depths, and the basic capability of the dredge plant to pick up and pump the dredged material the distance required. Wide fluctuations in flow conditions, particularly the density of slurry pumped, are very common in this type of dredging operation where the fundamental objective is to attain navigational channel depths within a specific area and cross-sectional prism. These fluctuations often cause instantaneous variation in pump power and speed that must be carefully controlled and partially compensated for in order to avoid overloading the prime mover, and/or excessive vibration and water hammer that can result in breakdowns or other disruptions in flow. Under these conditions, a multiple booster system employing a large number (generally more than two) of pumps cannot reliably be controlled and operated (as a whole) within reasonable limits of effectiveness. It is considered that the primary unit feeding a hydraulic multiple booster system for the long distance transport of dredged materials must be capable of controlling the density of intake material within much narrower limits than is possible by a cutterhead dredge during normal channel dredging operations. Thus, in this study, wherever a hydraulic transport system is utilized, such a system or concept includes equipment or techniques which provide for effective control of the slurry density.

Under item 2 above, it may appear that costs might be reduced if the installed system were left in place and reused for the next periodic requirement for dredging the navigation channel. Such a plan would be most difficult to implement because of the requirement to conform with the Corps' general policy to accomplish its dredging work by contract whenever reasonable prices can be obtained and the work performed in a timely manner. (The Corps does perform work with government owned dredges but this is mostly limited to specialized plants such as hopper dredges.)

In conformance with this policy, the greater part of the Corps work is advertisied for competitive bids and award is usually made to the lowest bidder who is responsive to the specifications, the bid is within the acceptable cost limitation, and the bidder is otherwise considered qualified and capable of performing the work. A successful contractor on a bid would own or control the dredging equipment, booster pumps, and pipeline, and after completion of the work would probably remove the equipment for use on other work. There would be no monetary advantage to the contractor to leave equipment in place; in fact, a significant monetary loss might be more likely if the equipment were left in place for possible bidding on the next periodic work at this location. The length of time between jobs during which maintenance and standby costs would be compounded, and the fact that there is no assurance that he would be the successful bidder on the repeat job would influence most contractors to dismantle the installation at the completion of the work. The alternative of construction by the Corps of a permanent pipeline and booster system would not be feasible, because it could not be made compatible with the different characteristics (pump size and horsepower) of the equipment owned by dredging contractors without sacrificing the competitive element in the bidding process.

The above analysis leads to the obvious conclusion that in hydraulic pipeline dredging operations associated with the Corps' channel navigation improvement and maintenance dredging operations, the use of more than two booster stations (say about 5 miles) would greatly accelerate increases in unit dredging costs (item 2 above) and, therefore, would not be practical. It would also result in unacceptable compounded delays in the dredging process and seriously affect and jeopardize the timely accomplishment of the navigation channel dredging (tems 3 and 4 above). On this basis, the hydraulic pipeline dredging operation with its inherent transport subsystem must

be divorced from the long distance transport system. Therefore, the long distance transport system must be considered as commencing in the disposal area (be it intermediate or otherwise) where the dredged material is deposited by the hydraulic dredge.

Hopper Dredge Operation

The basic hopper dredge operation involves the hydraulic excavation of bottom material by means of a dragarm suspended from a swivel joint at the side of the dredge. The dragarm is connected to a centrifugal pump located within the dredge. The draghead moves over the bottom as the vessel travels up and down the channel and dredges the material. The pump discharges the material into large hopper bins within the vessel and when the load therein is considered to be the economical maximum, the dredge then transports the material to the selected place of disposal. There are three alternative disposal procedures which are outlined and discussed below.

1. The material is bottom dumped in the waterway.
2. The material is bottom dumped into an open or unconfined basin for rehandling by auxiliary plant for upland disposal.
3. The material is rehandled by direct pumpout from the dredge and transported to an upland disposal area.

Alternative 1

The location where the material is bottom dumped is the final disposal site. The operation is therefore considered complete and of no concern to this study since upland disposal is not involved.

Alternative 2

Since the material is being dumped into an unconfined basin, a practice which has been phased out by the Corps of Engineers because of adverse environmental effects, this type of operation will not be addressed in this study.

Alternative 3

If the material is to be rehandled and transported to a nearby adjacent disposal area by direct pumpout, the operation is considered to be complete and of no concern to this study since no long distance transport is involved. However, if the material is pumped out of the dredge and transported a long distance to an upland site, such a transport system is of concern to this study. In this connection it must be noted that a hopper dredge serves as both the dredging plant and the transport vehicle, but the preponderance of costs are generated by the dredging features of the plant. Thus, when the dredge is engaged in the transport phase of the operation, such as proceeding to a disposal or pumpout site, the costs for such a single purpose operation are greatly in excess of the costs which would be incurred by other transportation modes such as tugs and scows. It is the general practice, therefore, to locate disposal sites as close to the dredging areas as practical and not to intentionally use the hopper dredge as a transport vehicle to haul the material to distant disposal sites. Accordingly, this phase of the study will be on the basis that all direct pumpout sites will not be located beyond the point that intentional use of the hopper dredge as a transport vehicle is involved.

Thus, for hopper dredge operations conducted for purposes of dredging navigation channels, and where long distance transport is involved, the dredging/transport system would involve the dredging of the navigation channel with direct pumpout from a nearby mooring site for transport to a distant upland disposal area via a multiple booster system. The feasibility of such a system is analyzed and discussed below.

In this system the dredged material would be transported in the hopper dredge to a nearby tie-up facility, and the material pumped directly from the hoppers through a pipeline to the upland

disposal area. It is obvious that in such a system the operation is not complete until the material is removed from the hoppers so that the dredge can return to the dredging site and resume its channel dredging operations. The dredging and pumpout operations cannot be separated and must, therefore, be considered as one. However, a most important consideration is the feasibility of pumping the material from the dredge directly through a multiple booster system to the long distance disposal area.

The basic consideration underlying the use of multiple booster pumps in the system is the effect of shutdowns or breakdowns in the booster plant on the hopper dredging operations. Since under this plan the dredging system and transport system (including boosters) are integral and inseparable parts in the complete system, a delay or interruption of any of its segments affects the entire system. Further, the additional time delay resulting from the need to clear or wash the line after each dredge pumpout operation, depending on the nature of the material being pumped, could become a most critical factor. The time that the dredge is available for productive dredging might be reduced to the point where it would not be adequate to keep pace with the channel shoaling rate. Another factor which must be considered is the cost of the dredging operation. Hopper dredges are the most costly dredges to construct and operate. To make hopper dredges cost effective, actual productive dredging time must be maximized, there being very little latitude for interruptions in the dredging process or compounding of delays in any part of the system. It is concluded, therefore, that the use of multiple booster systems in conjunction with the pumpout capability of the hopper dredge is not a practicable or cost effective means of providing long distance transport of dredged material. Such a system will, therefore, not be considered further in this study. The only practical alternative is to pump the material from the dredge into a nearby disposal area located within the pumpout capability of the dredge; further rehandling

of the material by other means would be employed to transport the material to the distant disposal area. On this basis the nearby disposal area (intermediate disposal area) is considered to be the commencement of the transport system.

It should be noted that there is one other type of dredging transport system that could be employed with hopper dredge operations for long distance transport. Such system would transport the dredged material by hopper dredge to a confined or partially enclosed dump basin. The dredged material would be bottom dumped within the basin and rehandled hydraulically for long distance transport by means of special plant. In essence the basin is the intermediate disposal area. This analogy also applies to the use of mechanical dredges where the dredged material is transported in scows to a confined or enclosed dump basin.

Mechanical Dredge Operation

This category of dredges includes clamshell, dipper, and bucket ladder dredges. These dredges operate basically on the principle of excavating the navigation channel by mechanically scooping bottom material by means of some form of bucket and depositing the material into scows or barges generally moored alongside the dredge. The ladder dredge performs this operation by means of buckets attached to an endless chain; the clamshell dredge by means of a clamshell bucket suspended by cable from a boom on the dredge; the dipper dredge by means of a bucket scoop at the end of a dipper stick pivoting from a framed boom. Since the basic function of all these dredges is to load scows and barges with the dredged material, a hydraulic pipeline dredge when operating as a scow loading dredge falls within the category of mechanical dredges and will be considered within this grouping when operating in this manner. After the scows or barges are loaded by the mechanical dredges, they are transported to an unloading site. The site could be either of the following:

1. A bottom dump site for final disposal. This could be an ocean disposal ground or an inland waterway site. In either case, the operation is complete after dumping and since no upland disposal is involved, this type of operation is of no concern to this study. The use of an open or unconfined rehandling basin for bottom dumping of the dredged material for further rehandling by auxiliary hydraulic plant to an upland disposal site has generally been phased out by the Corps of Engineers, the circumstances being the same as for hopper dredges. Accordingly, this study will not address operations involving the use of open rehandling basins.

2. A mooring site where the material in the scows or barges is removed by an independent unloader for eventual disposal at a final upland site. If the final disposal site is located within a relatively short distance of the dredging site, such a transport system will not be within the scope of this study (since long distance transport would not be involved). However, where the final disposal site is a long distance from the dredging site, such a transport system is germane to the study and is addressed appropriately. In this type of activity the operations of the basic dredging plant and the unloader must be at optimum synchronization since these units are completely dependent on each other for efficient and continuous operation. Any delay or interruption in the unloading operation would delay the return and availability of scows to the dredging plant. Thus, protracted delays in the unloading operation could seriously affect the ability of the dredging plant to maintain the navigation channel. If the unloading operation involves a series of booster stations, the probability of compounding delays or interruptions would be increased significantly and could be of sufficient magnitude that its adverse effect on the dredging operation could not be tolerated. On this basis, the mechanical dredging operation should be independent of the long distance transport system and an intermediate nearby disposal area incorporated

for the temporary deposit of the dredged material. The long distance transport system will then be considered as commencing at this intermediate disposal area.

The above overview establishes that the long distance transport systems commence at an existing or intermediate disposal area for all types of dredging operations and identifies some of the more important considerations associated with these transport systems. It also establishes and justifies the premise that in navigation channel dredging by hydraulic pipeline dredging equipment no more than two booster stations should be considered when the dredged material is pumped directly to an upland disposal area.

Appendix B

COMPUTER OUTPUTS FOR THE MOST PROBABLE CASE

(1500/1200 Grams per Liter and 1600/1400 Grams per Liter)

DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1500
SLURRY DENSITY (GRAMS PER LITER) 1200
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 500000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA						
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS		2.50	2.50	2.50	2.50	2.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC		1.40	1.40	1.40	1.40	1.40
CRITICAL VELOCITY - FT/SEC	1.20	9.0	10.0	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC		5.37	8.40	12.44	17.42	23.33
PERCENT OPERATING TIME		26	16	11	8	6
FRICTION COEFFICIENT	1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT		500	500	500	500	500
BOOSTER STATION SPACING - FT		14342	14624	14964	15139	15440
RHP PER PUMP		304	401	706	908	1323
EFFECTIVE LIFE OF PIPE - YRS		13.4	20.0	20.0	20.0	20.0
COST DATA - DOLLARS						
COSTS WHICH VARY WITH DISTANCE						
BOOSTER LABOR/1000 FT/YR		435	270	180	127	93
BOOSTER PLANT/1000 FT/YR (EXTRA PUMP)	1.30	4296	5620	7256	9357	11712
ENERGY/1000 FT/YR		1162	1139	1114	1101	1079
PIPE LAYING/1000 FT/YR	1.10	1644	1702	1759	1816	1873
PIPE STEEL/1000 FT/YR		1183	1094	1383	1704	2055
SUBTOTAL		8720	9833	11692	14105	16812
COSTS INDEPENDENT OF DISTANCE						
DREDGE PLANT/YR		400000	450000	500000	550000	600000
DREDGE LABOR/YR		233960	148023	100915	72050	53027
SUBTOTAL		633960	598023	600915	622050	653027

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000		1505960	1581323	1778115	2032558	2335027
(COST PER CU YD)		(3.01)				
200,000		2377960	2564623	2939315	3443058	4016227
(COST PER CU YD)		(4.76)				
300,000		3249960	3547923	4108515	4853558	5697427
(COST PER CU YD)		(6.50)				
400,000		4121960	4531223	5277715	6264058	7378627
(COST PER CU YD)		(8.24)				
500,000		4993960	5514523	6446915	7674558	9059827
(COST PER CU YD)		(9.99)				

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DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1500
SLURRY DENSITY (GRAMS PER LITER) 1200
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 1000000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA						
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS		2.50	2.50	2.50	2.50	2.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC		2.79	2.79	2.79	2.79	2.79
CRITICAL VELOCITY - FT/SEC	1.20	9.8	10.8	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC		5.37	8.40	12.44	17.42	23.33
PERCENT OPERATING TIME		52	33	22	16	12
FRICTION COEFFICIENT	1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT		500	500	500	500	500
BOOSTER STATION SPACING - FT		14342	14624	14964	15139	15440
BHP PER PUMP		304	401	706	900	1323
EFFECTIVE LIFE OF PIPE - YRS		6.7	10.6	15.5	20.0	20.0
COST DATA - DOLLARS						
COSTS WHICH VARY WITH DISTANCE						
BOOSTER LABOR/1000 FT/YR		870	540	360	254	106
BOOSTER PLANT/1000 FT/YR (EXTRA PUMP)	1.30	4296	5620	7256	9357	11712
ENERGY/1000 FT/YR		2324	2279	2227	2201	2159
PIPE LAYING/1000 FT/YR	1.10	1644	1702	1759	1816	1873
PIPE STEEL/1000 FT/YR		2275	1911	1715	1704	2055
SUBTOTAL		11409	12052	13317	15332	17905
COSTS INDEPENDENT OF DISTANCE						
DREDGE PLANT/YR		400000	450000	500000	550000	600000
DREDGE LABOR/YR		467935	296046	201030	144116	107653
SUBTOTAL		867935	746046	701030	694116	707653

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ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000 (COST PER CU YD)		2008835	1952046 (1.95)	2033530	2227316	2506153
200,000 (COST PER CU YD)		3149735 (3.15)	3158046	3365230	3760516	4304653
300,000 (COST PER CU YD)		4290635 (4.29)	4364046	4696930	5293716	6103153
400,000 (COST PER CU YD)		5431535 (5.43)	5570046	6028630	6826916	7901653
500,000 (COST PER CU YD)		6572435 (6.57)	6776046	7360330	8360116	9700153

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DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1500
SLURRY DENSITY (GRAMS PER LITER) 1200
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 2000000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA						
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS		2.50	2.50	2.50	2.50	2.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC		5.50	5.50	5.50	5.50	5.50
CRITICAL VELOCITY - FT/SEC	1.20	9.0	10.0	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC		5.37	8.50	12.44	17.42	23.33
PERCENT OPERATING TIME			66	45	32	24
FRICTION COEFFICIENT	1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT		500	500	500	500	500
BOOSTER STATION SPACING - FT			14624	14964	15139	15440
BHP PER PUMP			401	706	988	1323
EFFECTIVE LIFE OF PIPE - YRS		8.0	5.3	7.7	10.0	14.5
COST DATA - DOLLARS						
COSTS WHICH VARY WITH DISTANCE						
BOOSTER LABOR/1000 FT/YR			1000	719	500	372
BOOSTER PLANT/1000 FT/YR (EXTRA PUMP)	1.30		5620	7256	9357	11712
ENERGY/1000 FT/YR			4550	4454	4403	4317
PIPE LAYING/1000 FT/YR	1.10		1702	1759	1016	1073
PIPE STEEL/1000 FT/YR			3736	3222	2092	2691
SUBTOTAL			16704	17410	18976	20965
COSTS INDEPENDENT OF DISTANCE						
DREDGE PLANT/YR			450000	500000	550000	600000
DREDGE LABOR/YR			592093	403661	288233	215307
SUBTOTAL			1042093	903661	838233	815307

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ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000			2712493	2644661	2735833	2911087
(COST PER CU YD)				(1.32)		
200,000			4382893	4385661	4633433	5088307
(COST PER CU YD)			(2.19)			
300,000			6053293	6126661	6531033	7104087
(COST PER CU YD)			(3.03)			
400,000			7723693	7867661	8428633	9201387
(COST PER CU YD)			(3.86)			
500,000			9394093	9608661	10326233	11297087
(COST PER CU YD)			(4.70)			

DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1500
SLURRY DENSITY (GRAMS PER LITER) 1200
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 3000000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA						
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS		2.50	2.50	2.50	2.50	2.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC		0.37	0.37	0.37	0.37	0.37
CRITICAL VELOCITY - FT/SEC	1.20	9.9	10.8	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC		5.37	8.50	12.44	17.42	23.33
PERCENT OPERATING TIME			99	67	40	36
FRICTION COEFFICIENT	1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT		500	500	500	500	500
BOOSTER STATION SPACING - FT			14625	14965	15139	15440
BHP PER PUMP			481	706	980	1323
EFFECTIVE LIFE OF PIPE - YRS		0.0	3.5	5.2	7.2	9.7
COST DATA - DOLLARS						
COSTS WHICH VARY WITH DISTANCE						
BOOSTER LABOR/1000 FT/YR			1620	1079	762	550
BOOSTER PLANT/1000 FT/YR (EXTRA PUMP)	1.30		5620	7256	9357	11712
ENERGY/1000 FT/YR			6037	6601	6604	6476
PIPE LAYING/1000 FT/YR	1.10		1702	1759	1816	1873
PIPE STEEL/1000 FT/YR			5600	4794	4223	3065
SUBTOTAL			21475	21569	22762	24404
COSTS INDEPENDENT OF DISTANCE						
DREDGE PLANT/YR			450000	500000	550000	600000
DREDGE LABOR/YR			880139	605491	432349	322960
SUBTOTAL			1330139	1105491	982349	922960

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ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000			3405639	3262391	3250549	3371360
(COST PER CU YD)					(1.09)	
200,000			5633139	5419291	5534749	5819760
(COST PER CU YD)				(1.81)		
300,000			7700639	7576191	7810949	8268160
(COST PER CU YD)				(2.53)		
400,000			9920139	9733091	10087149	10716560
(COST PER CU YD)				(3.24)		
500,000			12075639	11889991	12363349	13164960
(COST PER CU YD)				(3.96)		

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DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER)	1500
SLURRY DENSITY (GRAMS PER LITER)	1200
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR)	4000000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA						
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS		2.50	2.50	2.50	2.50	2.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC		11.16	11.16	11.16	11.16	11.16
CRITICAL VELOCITY - FT/SEC	1.20	9.0	10.0	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC		5.37	8.50	12.44	17.42	23.33
PERCENT OPERATING TIME				90	64	48
FRICTION COEFFICIENT	1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT		500	500	500	500	500
BOOSTER STATION SPACING - FT				14964	15139	15440
BHP PER PUMP				706	900	1323
EFFECTIVE LIFE OF PIPE - YRS		0.0	0.0	3.9	5.4	7.3
COST DATA - DOLLARS						
COSTS WHICH VARY WITH DISTANCE						
BOOSTER LABOR/1000 FT/YR				1439	1015	744
BOOSTER PLANT/1000 FT/YR (EXTRA PUMP)	1.30			7256	9357	11712
ENERGY/1000 FT/YR				8909	8806	8634
PIPE LAYING/1000 FT/YR	1.10			1759	1816	1873
PIPE STEEL/1000 FT/YR				6430	5591	5061
SUBTOTAL				25793	26505	28024
COSTS INDEPENDENT OF DISTANCE						
DREDGE PLANT/YR				500000	550000	600000
DREDGE LABOR/YR				807322	576465	430613
SUBTOTAL				1307322	1126465	1030613

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000				3806622	3704965	3833813
(COST PER CU YD)					(.95)	
200,000				6465922	6443465	6635413
(COST PER CU YD)					(1.61)	
300,000				9045222	9181965	9437813
(COST PER CU YD)				(2.26)		
400,000				11624522	11760465	12240213
(COST PER CU YD)				(2.91)		
500,000				14203022	14418965	15042613
(COST PER CU YD)				(3.55)		

DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1600
SLURRY DENSITY (GRAMS PER LITER) 1400
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 500000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM		FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA							
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS			1.50	1.50	1.50	1.50	1.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC			.04	.04	.04	.04	.04
CRITICAL VELOCITY - FT/SEC		1.20	9.0	10.0	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC			5.37	8.50	12.44	17.42	23.33
PERCENT OPERATING TIME			16	10	7	5	4
FRICTION COEFFICIENT		1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT			500	500	500	500	500
BOOSTER STATION SPACING - FT			14342	14624	14964	15139	15440
BHP PER PUMP			355	561	823	1153	1544
EFFECTIVE LIFE OF PIPE - YRS			20.0	20.0	20.0	20.0	20.0
COST DATA - DOLLARS							
COSTS WHICH VARY WITH DISTANCE							
BOOSTER LABOR/1000 FT/YR			261	162	100	76	56
BOOSTER PLANT/1000 FT/YR	(EXTRA PUMP)	1.30	4710	6270	8176	10630	13383
ENERGY/1000 FT/YR			813	798	788	770	755
PIPE LAYING/1000 FT/YR		1.10	1644	1702	1759	1816	1873
PIPE STEEL/1000 FT/YR			836	1094	1383	1704	2055
SUBTOTAL			8264	10026	12206	14996	18122
COSTS INDEPENDENT OF DISTANCE							
DREDGE PLANT/YR			400000	450000	500000	550000	600000
DREDGE LABOR/YR			140301	80014	60549	43235	32296
SUBTOTAL			540301	530014	560549	593235	632296

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ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000		1366781	1541414	1781149	2092035	2444496
(COST PER CU YD)		(2.73)				
200,000		2193181	2544014	3001749	3592435	4256696
(COST PER CU YD)		(4.39)				
300,000		3019581	3546614	4222349	5092035	6068896
(COST PER CU YD)		(6.04)				
400,000		3845981	4549214	5442949	6591635	7881096
(COST PER CU YD)		(7.69)				
500,000		4672381	5551814	6663549	8891235	9693296
(COST PER CU YD)		(9.34)				

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DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1600
SLURRY DENSITY (GRAMS PER LITER) 1400
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 1000000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM		FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA							
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS			1.50	1.50	1.50	1.50	1.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC			1.67	1.67	1.67	1.67	1.67
CRITICAL VELOCITY - FT/SEC		1.20	9.8	10.8	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC			5.37	8.48	12.44	17.42	23.33
PERCENT OPERATING TIME			31	20	13	10	7
FRICTION COEFFICIENT		1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT			500	500	500	500	500
BOOSTER STATION SPACING - FT			14342	14624	14964	15139	15440
BHP PER PUMP			355	561	823	1153	1544
EFFECTIVE LIFE OF PIPE - YRS			11.1	17.6	20.0	20.0	20.0
COST DATA - DOLLARS							
COSTS WHICH VARY WITH DISTANCE							
BOOSTER LABOR/1000 FT/YR			522	324	216	152	112
BOOSTER PLANT/1000 FT/YR	(EXTRA PUMP)	1.30	4710	6270	8176	10630	13303
ENERGY/1000 FT/YR			1627	1595	1559	1541	1511
PIPE LAYING/1000 FT/YR		1.10	1644	1702	1759	1816	1873
PIPE STEEL/1000 FT/YR			1395	1217	1383	1704	2055
SUBTOTAL			9898	11108	13093	15843	18934
COSTS INDEPENDENT OF DISTANCE							
DREDGE PLANT/YR			400000	450000	500000	550000	600000
DREDGE LABOR/YR			208761	177620	121098	86470	64592
SUBTOTAL			608761	627620	621098	636470	664592

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ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000 (COST PER CU YD)		1670561 (1.67)	1730420	1930390	2220770	2557992
200,000 (COST PER CU YD)		2660361 (2.66)	2849220	3239690	3805070	4451392
300,000 (COST PER CU YD)		3650161 (3.65)	3960020	4540990	5309370	6344792
400,000 (COST PER CU YD)		4639961 (4.64)	5070020	5850290	6973670	8230192
500,000 (COST PER CU YD)		5629761 (5.63)	6181620	7167590	8557970	10131592

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DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1600
SLURRY DENSITY (GRAMS PER LITER) 1400
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 2000000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM		FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA							
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS			1.50	1.50	1.50	1.50	1.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC			3.35	3.35	3.35	3.35	3.35
CRITICAL VELOCITY - FT/SEC		1.20	9.8	10.8	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC			5.37	8.50	12.44	17.42	23.33
PERCENT OPERATING TIME			62	39	27	19	14
FRICTION COEFFICIENT		1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT			500	500	500	500	500
BOOSTER STATION SPACING - FT			14342	14624	14964	15139	15440
BHP PER PUMP			355	561	823	1153	1544
EFFECTIVE LIFE OF PIPE - YRS			5.6	8.8	12.9	18.1	20.0
COST DATA - DOLLARS							
COSTS WHICH VARY WITH DISTANCE							
BOOSTER LABOR/1000 FT/YR			1044	648	432	305	223
BOOSTER PLANT/1000 FT/YR	(EXTRA PUMP)	1.30	4710	6270	8176	10630	13383
ENERGY/1000 FT/YR			3253	3191	3118	3082	3022
PIPE LAYING/1000 FT/YR		1.10	1644	1702	1759	1816	1873
PIPE STEEL/1000 FT/YR			2732	2266	2011	1852	2055
SUBTOTAL			13383	14077	15496	17685	20556
COSTS INDEPENDENT OF DISTANCE							
DREDGE PLANT/YR			400000	450000	500000	550000	600000
DREDGE LABOR/YR			561522	355256	242197	172940	129104
SUBTOTAL			961522	805256	742197	722940	729104

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000 (COST PER CU YD)		2299822	2212956 (1.11)	2291797	2491440	2784784
200,000 (COST PER CU YD)		3638122	3620656 (1.81)	3841397	4259940	4840384
300,000 (COST PER CU YD)		4976422 (2.49)	5028356	5390997	6028440	6895984
400,000 (COST PER CU YD)		6314722 (3.16)	6436056	6940597	7796940	8951584
500,000 (COST PER CU YD)		7653022 (3.83)	7843756	8490197	9565440	11007184

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DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1600
SLURRY DENSITY (GRAMS PER LITER) 1400
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 3000000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA						
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS		1.50	1.50	1.50	1.50	1.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC		5.02	5.02	5.02	5.02	5.02
CRITICAL VELOCITY - FT/SEC	1.20	9.8	10.8	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC		5.37	8.50	12.44	17.42	23.33
PERCENT OPERATING TIME		94	59	40	29	22
FRICTION COEFFICIENT	1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT		500	500	500	500	500
BOOSTER STATION SPACING - FT		14342	14624	14964	15139	15440
BHP PER PUMP		355	561	823	1153	1544
EFFECTIVE LIFE OF PIPE - YRS		3.7	5.9	8.6	12.0	16.1
COST DATA - DOLLARS						
COSTS WHICH VARY WITH DISTANCE						
BOOSTER LABOR/1000 FT/YR		1566	972	647	457	335
BOOSTER PLANT/1000 FT/YR (EXTRA PUMP)	1.30	4710	6270	8176	10630	13303
ENERGY/1000 FT/YR		4808	4706	4677	4623	4533
PIPE LAYING/1000 FT/YR	1.10	1644	1702	1759	1816	1873
PIPE STEEL/1000 FT/YR		5174	3361	2915	2630	2450
SUBTOTAL		16974	17091	18174	20156	22502
COSTS INDEPENDENT OF DISTANCE						
DREDGE PLANT/YR		400000	450000	500000	550000	600000
DREDGE LABOR/YR		842203	532004	363295	259409	193776
SUBTOTAL		1242203	982004	863295	809409	793776

ITEM	FACTOR	PIPELINE DIAMETER - INCHES				
		10	12	14	16	18
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000		2939683	2691984	2680695	2825089	3051976
(COST PER CU YD)				(.89)		
200,000		4637083	4401084	4498095	4840689	5310176
(COST PER CU YD)			(1.47)			
300,000		6334483	6110184	6315495	6856289	7568376
(COST PER CU YD)			(2.04)			
400,000		8031883	7819284	8132895	8871889	9826576
(COST PER CU YD)			(2.61)			
500,000		9729283	9528384	9950295	10887489	12084776
(COST PER CU YD)			(3.18)			

DESIGN AND COST DATA SUMMARY

IN SITU DENSITY (GRAMS PER LITER) 1600
SLURRY DENSITY (GRAMS PER LITER) 1400
DISPOSAL AREA PRODUCTION (CU YDS PER YEAR) 4000000

FACTORS: VELOCITY 1.20 ENERGY 1.00 FRICTION 1.10

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	18
DESIGN DATA						
RATIO OF DISPOSAL AREA SOLIDS TO SLURRY SOLIDS		1.50	1.50	1.50	1.50	1.50
QUANTITY OF SLURRY FOR DISPOSAL AREA PRODUCTION - CU FT/SEC		6.70	6.70	6.70	6.70	6.70
CRITICAL VELOCITY - FT/SEC	1.20	9.8	10.8	11.6	12.5	13.2
QUANTITY OF SLURRY AT CRITICAL VELOCITY - CU FT/SEC		5.37	8.48	12.44	17.42	23.33
PERCENT OPERATING TIME			79	54	38	29
FRICTION COEFFICIENT	1.10	.031	.031	.031	.031	.031
TOTAL DISCHARGE HEAD - FT		500	500	500	500	500
BOOSTER STATION SPACING - FT			14624	14964	15139	15440
HHP PER PUMP			561	823	1153	1544
EFFECTIVE LIFE OF PIPE - YRS		0.0	4.4	6.5	9.0	12.1
COST DATA - DOLLARS						
COSTS WHICH VARY WITH DISTANCE						
BOOSTER LABOR/1000 FT/YR			1296	863	609	446
BOOSTER PLANT/1000 FT/YR (EXTRA PUMP)	1.30		6270	8176	10630	13383
ENERGY/1000 FT/YR			6381	6236	6164	6044
PIPE LAYING/1000 FT/YR	1.10		1702	1759	1816	1873
PIPE STEEL/1000 FT/YR			4501	3843	3420	3158
SUBTOTAL			20150	20877	22639	24904
COSTS INDEPENDENT OF DISTANCE						
DREDGE PLANT/YR			450000	500000	550000	600000
DREDGE LABOR/YR			710511	404393	345879	250360
SUBTOTAL			1160511	904393	895879	850360

ITEM	FACTOR	PIPELINE DIAMETER - INCHES 10	12	14	16	19
TOTAL COSTS FOR VARIABLE DISTANCES - DOLLARS						
DISTANCE - FEET						
100,000			3175511	3072093	3159779	3340760
(COST PER CU YD)				(.77)		
200,000			5190511	5159793	5423679	5839160
(COST PER CU YD)				(1.29)		
300,000			7205511	7247493	7687579	8329560
(COST PER CU YD)			(1.80)			
400,000			9220511	9335193	9951479	10819960
(COST PER CU YD)			(2.31)			
500,000			11235511	11422893	12215379	13310360
(COST PER CU YD)			(2.81)			

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Souder, Paul S

Dredged material transport systems for inland disposal and/or productive use concepts / by Paul S. Souder, Jr. ... [et al.], General Research Corporation, McLean, Virginia. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

314 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-28)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW 39-76-C-0026 (DMRP Work Unit No. 3B01)

Bibliography: p. 261-281.

1. Dredged material. 2. Dredged material disposal. 3. Dredging. 4. Transportation. I. General Research Corporation. II. United States. Army. Corps of Engineers. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-28.
TA7.W34 no.D-78-28